ICTEAM is a research institute of the Université catholique de Louvain. The institute is currently home for more than 40 professors and more than 200 researchers who carry out both basic and applied research in key fields of information and communication technologies, electronics, computer science and applied mathematics.

Throughout this document, we highlight some of our recent, most remarkable scientific achievements and we illustrate successful technology transfer results via patents issued and several spin-offs initiated by ICTEAM members. An overview of our activities is provided by the list of the public PhD defenses that took place in 2015 and 2016 and the prizes and awards granted to our members over the last years.

Prof. Jean-Didier Legat
Head of ICTEAM

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PRIZES AND AWARDS


- **Quentin Cappart et al.** – Third Prize of the IEEE Region 8 Student Paper Contest at the IEEE R8 EUROCON 2015 Conference. September 2015.

- **Laurent Francis, Denis Flandre et al.** – Innovation Award Competition for FP7 Participants for their FP7 project “SOI-HITS” with Nicolas André, Pierre Gérard and other UCL researchers, CISSOID (UCL spin-off) and 6 other European partners. December 2015.

- **Laurent Francis, Numa Couniot and Denis Flandre** – Best Poster Award, 4th International Symposium on Sensor Science (I3S). July 2015.


- **Claude Oestges** – Chair of the COST Action CA15014 “Inclusive Radio Communication Networks for 5G and beyond (IRACON)” (April 2016) and IEEE Fellow for contributions to channel characterization and modeling for multiple-input multiple-output wireless communications (November 2015).


- **Matthew Philippe** – Finalist of the Best Student Paper Award at the joint ACM/IEEE conference HSCC 2015: Hybrid Systems, Computation and Control. April 2015.


- **Jean-Pierre Raskin** – Médaille André Blondel for his research in the field of RF SOI (Silicon-on-Insulator). December 2015.

- **Paul Van Dooren** – Hans Schneider Award of the International Linear Algebra Society (ILAS) for his outstanding lifetime contribution to Linear Algebra and 2016 Outstanding Paper Award of the journals of the Society of Industrial and Applied Mathematics (SIAM). July 2016.

- **Axel van Lamsweerde** – Member of the Scientific Board of INRIA (November 2015) and Lifetime Service Award granted by the Steering Committee of the IEEE International Requirements Engineering Conference Series for “visionary leadership and ongoing services to the community” (August 2015).

- **Peter Van Roy** – Member of Scientific Council, IRCAM (Institut de Recherche et Coordination Acoustique/Musique), 2007-present.

- **John A. Lee, Michel Verleysen** – Best Paper Award at the IEEE Symposium on Computational Intelligence and Data Mining (CIDM), Orlando. December 2014.

- **Michel Verleysen** – IEEE Fellow for contributions to high-dimensional analysis and manifold learning. May 2015.

- **Stefano Vissicchio, Olivier Tilmans et al.** – Best Paper Award at SIGCOMM 2015. August 2015.
PHD DEFENSES


RESEARCH RESULTS

Electronic Circuits and Systems

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Ultra-low-power computing

Keywords: Microcontroller; Memory; Flip-flops; Adaptive circuits; 28 nm CMOS; IoT.

David Bol, Francois Stas, Thomas Haine, Ludovic Moreau, Guerric de Streef, Charlotte Frenkel, Khoi Nguyen, Denis Flandre, Jean-Didier Legat

Abstract – For a massive yet sustainable Internet-of-Things, ultra-low-power computing is required without compromising the data processing and storage performances. In the electronic circuits and systems (ECS) group, we pursue new solutions to this challenge with ultra-low-voltage (ULV) digital integrated circuit (IC) and system-on-chip (SoC) design. Latest results feature the evaluation of 28 nm FDSOI CMOS technology for ULV digital circuits and SRAM memories, adaptive back biasing techniques to compensate process and temperature variations and low-energy pulsed flip-flops in collaboration with CEA-LETI.

The connection of our daily life’s objects to the cloud according to the Internet-of-Things (IoT) vision is about to revolutionize the way we live. To enable this revolution, a massive deployment of sensor nodes is required with predictions announcing up to trillions of these nodes. Such a massive deployment is not environmentally and economically sustainable with current technologies. Some of the pitfalls lie in the computing capability of IoT nodes whose power consumption needs to be optimized in order to operate on ambient energy harvesting without compromising the data processing and storage performances [?]. Indeed, key applications using audio/vision sensing or brain-machine interfaces (Fig. ??) require the on-chip extraction of the important information from the sensed data to limit the worldwide electrical power consumption of the ICT infrastructure (datacenters and basestations) due to machine-to-machine (M2M) wireless data traffic. Therefore, the IoT nodes need to be able to perform compression, feature extraction or classification within their ultra-low power budget which is not possible with current low-power microcontroller (MCU) technologies because of their limited energy efficiency.

The energy cost of software execution can be avoided by adding key dedicated hardware accelerators to the MCU [?]. ULV operation can further improve the energy efficiency of the HW accelerators. Nevertheless, ULV operation comes at the expense of a degraded speed ultimately below the MHz deep in the subthreshold regime. To overcome the performance degradation, we rely on nanometer CMOS technologies [?] with high-speed design techniques for both logic and memories in 28 nm FDSOI CMOS including:

- the optimization of SRAM memories with respect to their dynamic and statistical stability [?],
- the generation of adaptive back biasing voltages to compensate process and temperature effects on the speed of logic and SRAM memories [?],
- the design of ultra-dense low-clock load pulsed flip-flops in collaboration with CEA-LETi (Grenoble, France) [?] and true-single-phase flip-flops.

Some of these techniques have been used to design a 0.4V ultra-low-power SRAM memory whose prototype codenamed MEMPHIS is under test (Fig. ??). Its dual-voltage divided-wordline architecture featuring the UCL patented ULP SRAM bitcell with adaptive back biasing and low-energy skewed sense amplifiers should allow 100-MHz operation with record access energy. Next research will focus on the design of a high-performance ULV MCU-based computing platform in 28 nm FDSOI CMOS.

Figure 1: Data processing and storage in IoT nodes need to perform compression, feature extraction of classification at an ultra-low power.

Figure 2: Die microphotograph of the MEMPHIS prototype in 28 nm FDSOI CMOS.

References


Abstract – For a massive yet sustainable Internet-of-Things, ultra-low-power sensing is required without compromising quality of the signal acquisition. CMOS imagers are one of the most difficult sensing devices to implement at ultra-low power due to the numerous pixels required. In the electronic circuits and systems (ECS) group, we pursue new solutions to this challenge with ultra-low-voltage (ULV) CMOS imager design. Latest results include a 0.5V imager successfully prototyped within a 3-mm$^2$ solar-powered video analysis System-on-Chip (SoC) codenamed SunPixer.

The connection of our daily life’s objects to the cloud according to the Internet-of-Things (IoT) vision is about to revolutionize the way we live. To enable this revolution, a massive deployment of sensor nodes is required with predictions announcing up to trillions of these nodes. Such a massive deployment is not environmentally and economically sustainable with current technologies. Some of the pitfalls lay in the sensing capability of IoT nodes whose power consumption needs to be optimized in order to operate on ambient energy harvesting while preserving sufficient acquisition quality for effective extraction of the meaningful information from the sensed data [1]. This is particularly challenging for multi-dimensional sensing devices such as CMOS image sensors for vision applications.

The first research we made in this area was the design of a 0.5V CMOS imager in 65nm CMOS for integration within the SunPixer SoC (Fig. 1), which is a 3-mm$^2$ solar-powered video analysis SoC. It features an inductorless indoor/outdoor energy-harvesting power management unit, a 50-MHz 32-bit microcontroller (MCU) for on-chip video/image analysis and a 128 × 128-pixel imager prototype. The imager uses digital pixel sensors (DPS) for time-based readout at 0.5V to reach record energy efficiency of 17pJ/frame.pixel. However, as the high transistor variability (mismatch) at ULV significantly degrades the image quality, we had to introduce key techniques to restore a 42dB dynamic range with two of them under patent application: wide-range adaptive body biasing [2], low-R$\text{ON}$ gating of the 2-transistor in-pixel comparator [3] and robust digital readout performing delta-reset sampling (Fig. 2). Extrapolation of these results to a VGA image resolution would give a power consumption of only 80$\mu$W at 15 frames per second, which corresponds to a power reduction of at least 400 × compared to the commercial state-of-the-art. SoC integration further allows avoiding the prohibitive energy cost of image transfer from a CMOS imager to an MCU chip through the external 1.8-2.5V I/O bus.

The second research in this field aims at transferring this design on a low-cost 0.18$\mu$m CMOS process with a VGA image resolution. A prototype CMOS imager codenamed CAMEL (Fig. 3) was designed in collaboration with nSilition (LLN, Belgium). The chip is currently under prototyping.

References


Ultra-low power management and voltage regulation

Keywords : Energy harvesting; Switched-capacitor converters; Linear regulators; IoT.

David Bol, Pierre-Antoine Haddad, Khoi Nguyen, Guerric de Streel, Denis Flandre

Abstract – For a massive yet sustainable Internet-of-Things, ultra-low power management and voltage regulation are required to operate the nodes on ambient energy harvesting (EH) while delivering the required supply voltages to the sensing, computing and communication blocks. Latest related results obtained in the electronic circuits and systems (ECS) group include indoor/outdoor solar EH power management units licensed to and industrialized by e-peas semiconductors, RF-harvesting rectifiers, a reconfigurable switched-capacitor converter with a wide load power range in collaboration with ST Microelectronics, a voltage reference with the record 0.2V minimum and an ultra-low-quietescent current linear regulator with most of them included in a 3-mm² solar-powered video analysis System-on-Chip (SoC) codenamed SunPixer.

The connection of our daily life’s objects to the cloud according to the Internet-of-Things (IoT) vision is about to revolutionize the way we live. To enable this revolution, a massive deployment of sensor nodes is required with predictions announcing up to trillions of these nodes. Such a massive deployment is not environmentally and economically sustainable with current battery-operated technologies. Indeed, to avoid the cost and the ecotoxicity of battery replacement, the IoT nodes need to operate by harvesting the ambient energy present in various forms: solar, thermoelectric, piezoelectric or electromagnetic RF [1].

Commercial energy-harvesting power management units (EH-PMU) fail to meet the demand for autonomous startup (cold start) when the energy storage is empty. A first EH-PMU for micro PV cells based on an inductive boost converter was designed with the specific target to provide robust cold start functionality and maximum power-point tracking while allowing to supply a wide range of off-the-shelf sensing, computing and communication components. It was licensed to e-peas semiconductors spin-off which successfully prototyped and industrialized it under its AEM product line [2]. A second EH-PMU for micro PV cells was designed based on a single bidirectional multi-gain/multi-mode switched-capacitor converter for direct harvester/load connection and on-chip integration in 65nm CMOS without external inductor [3]. It was integrated within the SunPixer SoC (Fig. 1), which is a 3-mm² solar-powered video analysis SoC.

RF electromagnetic energy from wireless communication signals is another interesting energy source in densely populated zones. Front-end interfaces for RF EH-PMU must include an AC/DC converter typically implemented by a rectifier. An optimization method for rectifiers has been developed and validated on the design of a 13.56-MHz rectifiers [4] using UCL-patented ULP diodes on simple Greinacher architecture and with more complex architectures (cross-coupled, differential drive).

From the system supply voltage generated by the EH-PMU, the specific ultra-low-voltage (ULV) load supplies need to be generated and regulated with circuits including:

- the first voltage reference circuit starting at a 0.2-V supply voltage that was successfully prototyped in 65nm CMOS [5],
- an ultra-low-quietescent current linear regulator with a high-dropout (HDO) architecture that was successfully prototyped in 65nm CMOS [6],
- a multi-mode switched-cap DC/DC converter for a wide output power range that was successfully prototyped in 28nm FDSOI CMOS [7] in collaboration with ST Micro (Crolles, France).

References

Ultra-low-power wireless communications

Abstract – For a massive yet sustainable Internet-of-Things, future ultra-low-power wireless communications are required without compromising connectivity. In the electronic circuits and systems (ECS) group, we pursue new solutions to this challenge with ultra-low-voltage RF integrated circuit (IC) and system-on-chip (SoC) design. Latest results feature a 0.55V IEEE 802.15.4a Impulse-Radio Ultra-Wideband (IR-UWB) transmitter successfully prototyped in 28nm FDSoI CMOS and 0.5V 0-6GHz noise-cancelling LNA for software-defined radio receivers.

The connection of our daily life’s objects to the cloud according to the Internet-of-Things (IoT) vision is about to revolutionize the way we live. To enable this revolution, a massive deployment of sensor nodes is required with predictions announcing up to trillions of these nodes. Such a massive deployment is not environmentally and economically sustainable with current technologies. Some of the pitfalls lay in the wireless communications of IoT nodes whose power consumption needs to be optimized in order to enable operation on ambient energy harvesting without compromising the connectivity [1]. Recent wireless solutions usually tackle the energy problem with low-duty cycled radios taking advantage of the ultra-low requirement on speed by the sensing application. However, key applications using audio/vision sensing or requiring low latency call for high datarates.

Impulse-Radio Ultra-Wideband (IR-UWB) is considered as a promising solution for high data-rate, short range and low-power solution due to the duty-cycled nature of the signal as well as the potential for low-complexity and low-power transmitter (TX) architectures. These characteristics have been the driving force behind the development of the IEEE 802.15.4a standard covering datarates from 0.11 to 27.24Mbps. In 2016, we propose a mostly-digital UWB transmitter System-on-Chip (SoC) codenamed SleepTalker, which was designed for ultra-low voltage in 28nm FDSoI CMOS compliant with the IEEE 802.15.4a standard. Operated at 0.55V, it achieves a record energy efficiency of 24pJ/bit (i.e. 650fJ/W at 27Mbps) with embedded power management, highly duty-cycled digital baseband and programmable pulse shaping. This is a 250 × improvement compared to the commercial state-of-the-art. Wide-range on-chip adaptive forward back biasing is implemented for threshold voltage reduction, compensation of process/temperature variations and tuning of both the carrier frequency and the output power. The TX shown in Fig. 1 occupies a core area of 0.93mm².

Another connectivity challenge comes from the massive deployment of IoT nodes. To avoid the congestion of the RF spectrum, cognitive communications based on software-defined reconfigurable radio (SDR) architectures covering bands up to 6 GHz are needed for agile wireless communications. On the receiver (RX) side, these radios impose though requirement on the low-noise amplifier (LNA) over a wide frequency range. In order to be integrated in complex SoCs, such LNAs should also be implemented in nanometer CMOS technologies to follow SoC development trends while benefiting from their high fr. This technology scaling, however, has led to a supply voltage reduction to maintain device reliability. The simultaneous threshold voltage reduction is not as fast in order to keep the leakage current manageable. Reducing the supply voltage of RF analog circuits to ensure compatibility with digital parts or to reduce the power consumption challenges the analog design due to the reduced voltage headroom.

We show, that reducing the supply voltage pushes devices from strong inversion to moderate inversion and that forward back biasing can be used to mitigate this trend and increase the design space. We also study the impact of technology scaling on important RF figures of merit to highlight the ability of advanced 28nm FDSoI CMOS to trade speed for power. We then illustrate this ability at circuit level by looking at the optimum sizing of a noise cancelling ultra-low-voltage wideband LNA targeting the hot topic of SDR [2]. For this LNA, which operating principle is illustrated in Fig. 2, we show that technology scaling and forward back biasing are shifting the minimum supply voltage limitation from the bandwidth constraint to the noise constraint.

References


Radiation-hardening of off-the-shelf FPGA systems

Abstract – Radiation-induced errors in electronic circuits, known as Single-Event Effects (SEEs), are critical in satellites as space is a radiative environment: ensuring the reliability of electronic devices raises a tradeoff between reliability, overhead and latency. In order to leverage high-performance and low-cost Commercial Off-The-Shelf (COTS) FPGAs in space applications, this work tackles fault tolerance among three abstraction levels: circuit, organization and control. We proposed a topology based on modern Xilinx Zynq System-on-Chip FPGAs. It offers strong circuit overhead reductions compared to the conventional Triple Modular Redundancy (TMR) and was successfully validated through fault injection simulation and proton beam-testing.

In space, circuits are particularly exposed to Single-Event Effects (SEEs), resulting from high-energy particles striking the silicon lattice, which induce soft errors through Single-Event Upsets (SEUs) in memory elements and Single-Event Transients (SETs) in combinatorial logic. Circuits dedicated to space applications must thus be made radiation-hardened using specific design techniques. As technology scales down to increase resource integration and reduce power, circuits become more vulnerable to upsets, up to the point that new challenges are posed by the occurrence of Multiple-Bit Upsets (MBUs) which cannot be further neglected. Compared to dedicated ASICs, the use of FPGAs in space applications reduces development costs, improves the time-to-market and allows for on-orbit reprogrammability, hence lowering the mission risk. There is an increasing interest in using Commercial Off-The-Shelf (COTS) SRAM-based FPGAs as they drastically improve performance over traditional radiation-hardened FPGAs, leading to a narrower required satellite communication bandwidth while further reducing costs. However, as the SRAM used to store the configuration bitstream is very sensitive to upsets, proper hardening techniques must be applied to protect both the user logic and the configuration memory.

As the power consumption impacts the battery size and thus the weight of the satellite, the main objective of our work is to design cost-driven fault-tolerance topologies with minimum resource and power overheads while ensuring full error handling, up to MBU hardening. In order to optimize the resulting tradeoff between reliability, overhead and latency, we proposed in [1] a new design methodology based on three abstraction levels: circuit, organization and control. An overview of the proposed hardening strategy is shown in Fig. 1, it is based on a modern Xilinx Zynq SoC FPGA which embeds an FPGA and an ARM Cortex A9 processor in the same die.

We proposed a key innovation at each abstraction level of our methodology. At the circuit level, a new ultra-low overhead Forward Temporal Redundancy (FTR) scheme was designed to detect errors in user logic at an overhead below that of Duplication With Comparison (DWC). At the organization level, this work leveraged the opportunities brought by frame- and module-based Dynamic Partial Reconfiguration (DPR) to handle configuration memory errors. At the control level, this work fully exploited the Xilinx Zynq SoC FPGA by offloading a circuit state preservation structure based on checkpointing and rollback to the embedded Cortex A9. Choosing a five-stage pipelined MIPS processor as a benchmark, our complete topology is far more efficient than a Triple Modular Redundancy (TMR) design and requires only 85% combinational and 125% sequential overheads. The detection and correction latencies are of 4.5 ms and 320 µs, respectively.

The proposed design was successfully validated in a two-fold process: fault-injection simulation was first conducted to verify the different concepts, then proton beam-testing was carried to simulate the particle strikes on the tested device (Fig. 2), which is the closest approximation to real space conditions [2]. Fault-injection predicted a 99.998% reliability, while beam testing reported only one system error over 493 logged SEEs, over which 147 were MBUs. It shows that, despite the low resource utilization of our design, full MBU hardening at a minimized latency penalty is reliably achieved.

Further research in this field targets the hardening of other critical points such as the golden bitstream memory, the clock distribution and the I/Os.

References


Enormous progress of the semiconductor technology during the last decades was driven by the continuous demand for the increase of the operation speed and the integration density of complex digital circuits. Aggressive device downscaling requests for employment of new materials and non-classical device architectures.

Nowadays, two main contenders are recognized as pretenders to satisfy ITRS requirements for the 20 nm device node and beyond:
- planar fully depleted (FD) Silicon-on-Insulator (SOI) with ultra-thin body and ultra-thin buried oxide (BOX): UTBB MOSFET;
- multiple-gate (MuG) MOSFET (FinFET and NanoWire FET).

Last year our team was involved in EU projects on the development of cutting-edge MOSFET technology with industrial and RI leaders in the European electronics (IMEC, CEA-Leti, ST Microelectronics (Fr), IMEC (Be). Thanks to this collaboration, EC and FNRS fundings, we had possibility to assess various advanced MOSFETs in the view of their further analog/RF applications [1]. Both UTBB and MuG architectures were revealed to be promising for mobile/wireless applications with LOP/LSTP options with a potential for improvements [1].

Device analog/RF performance was assessed through key figures such as transconductance ($g_m$), output conductance ($g_d$), intrinsic gain ($A_{in}$), cut-off frequencies ($f_T$, $f_{max}$). Particular attention was paid to parasitic elements and undesirable effects (self-heating (SH) and source-to-drain coupling through the substrate) whose impact on device performance increases enormously in downscaled devices. Specific features of UTBB FDSOI and MuGFET were analyzed.

We emphasized a crucial importance of wide-frequency DC-to-RF range characterization for fair device assessment and benchmarking. Relevant strength of this approach can be seen in some examples:

**Proper extraction of SH effect parameters.** SH effect in devices with various architectures and its impact on analog Figures of Merit (FoM) were analyzed [2-5]. Regardless thin-BOX (and thus expected SH reduction) in advanced MOSFETs, rather important channel temperature rise (~100 °C) was revealed [2-5]. Much higher thermal resistance was revealed in short-channel UTBB MOSFETs comparing to their bulk counterparts [5] (Fig.1). Nevertheless, regardless stronger heating of UTBB FDSOI devices they outperform bulk counterparts in terms of analog FoM [5] (Fig. 1).

**Parasitic coupling through the substrate** was analyzed both in planar devices with thin BOX and in triple gate devices [1, 2, 4]. It was shown that BOX thinning in advanced devices results in enhanced source-to-drain coupling through the substrate, which in terms of parameters degradation can become even more important than widely-discussed SH effect (Fig. 2) [2]. However, introduction of so-called Ground Plane (GP) (i.e. highly-doped layer underneath the BOX) was shown to efficiently suppress coupling through the substrate [1, 2, 4] (Fig. 2). In the case of triple-gate devices, fin width engineering also allows suppression of this effect [1] (Fig.2).

**Effect of extrinsic parasitic elements on advanced devices RF FoM.** The developed procedure is based on extraction of complete small-signal equivalent circuit from S-parameter measurements at different bias conditions [1, 6]. We demonstrated that impact of parasitic elements becomes crucial with device downscaling and introduction of new 3D/thin-films architectures, dominating device performance [1]. Separate extraction of extrinsic and intrinsic parameters helps to optimize process and device configuration. Appropriate optimization allowed 28FDSOI MOSFETs to achieve $f_T$ ~280 GHz, i.e. close to the ITRS requirements [4, 6].

**References**


Highly-sensitive CMOS capacitive biosensors towards detection of single bacterial cell in electrolyte solutions

Keywords: Biological sensors; CMOS circuits; Modelling; Simulation; Measurements.

Numa Couniot, Laurent Francis, Denis Flandre

For centuries, bacterial cells have been one of the major causes of human diseases, and are still responsible for several millions of deaths every year. Rapid detection and identification of pathogens in clinical, food or water samples is an important prerequisite step to establish a diagnosis and prevent the disease propagation. This work investigated how capacitive biosensors can be used for rapid, selective and sensitive pathogen detection in various biological buffers. Their integration with microfluidics, electrokinesis and CMOS technology is provided towards miniaturized and affordable lab-on-chips for point-of-care diagnosis tools.

The first part of the work studied the capacitive transduction, based on Al/Al2O3 interdigitated microelectrodes (IDEs). Real-time detection of Staphylococcus epidermidis in low-conductive solutions is experimentally shown, and explained by a comprehensive analytical model of the transducer. An innovative selectivity principle using lytic enzymes is then presented and shown to selectively detect of S. epidermidis among Enterococcus faecium cells in synthetic urine. Thanks to numerical simulations using Poisson-Nernst-Planck equations, the capacitive biosensor parameters are eventually optimized towards the maximal sensitivity.

The second part of the work investigated the use of electrokinetic effects to attract bacterial cells on the surface of capacitive biosensors. By using an annular-ring macroelectrode encompassing the IDEs, short and long-range trapping of S. epidermidis were observed and attributed to contactless dielectrophoresis and electrothermal flow, respectively. At 63 MHz precisely, a resonance effect related to device connectors was found to dramatically increase the trapping of S. epidermidis lowering the detection limit by two orders of magnitude. Analytical models and numerical simulations are provided to explain the observed phenomena.

The 3rd part of the work focused on the design of two analog circuits to interface on-chip capacitive biosensors in a 0.25-µm CMOS technology. The first is a capacitance-to-frequency converter working up to 575 MHz which demonstrates sensitivity to bacterial cells in high-conductive solutions. The second is a 16 × 16 capacitive biosensor array featuring micrometer-sized pixels to lower the absolute number of detectable bacteria to ca. 7. The innovative pixel architecture uses a capacitance-to-voltage converter followed by a gain stage to boost the sensitivity.

In conclusion, capacitive biosensors towards bacteria detection have extensively been studied in this work, first starting from the transduction principles and then integrating them into advanced electrophoretic and electronic systems. The innovations provided in this work offer interesting perspectives for the next generations of capacitive biosensors targeting point-of-care diagnosis of bacterial cells.

References


SOI sensing platforms optimized for water vapour and light detection

Keywords : Environmental sensors; CMOS circuits; Simulation; Measurements.

Nicolas André, Guoli Li, Pierre Gérard, Laurent Francis, Denis Flandre

Abstract – Miniature systems are highly required for in-situ monitoring of the environment, industrial processes... In this context, we develop two low-power sensors in SOI CMOS technology, with large temperature working range.

We report here the performances of two sensors based on the same micro-machined silicon-on-insulator (SOI) suspended platform [1]. Our motivation is to develop a low-cost, low-power and reliable sensor microsystem with integrated electronics interface for applications from ambient to high temperature (200 °C) [2]. Figure 1 presents the three functions embedded on the platform: (1) gas sensing with top electrodes, (2) heating with tungsten resistor for layer activation, drying, cleaning, temperature dependence cancellation and (3) diode for temperature and light measurements.

A water vapour sensor is based on coated electrodes embedded with its own temperature sensor. It exploits an atomic layer deposited 25nm-thick Al$_2$O$_3$ coating, in opposite to conventional polymer-based humidity sensors. The %RH variations are capacitively sensed, then converted to oscillating voltage period variations with a 200µW low power consumption. Figure 2 shows the sensor output under temperature and humidity variations from 25 to 85 °C and 35 to 95%RH. At 25 °C, the sensitivity to humidity is equal to ∼2.5%/%RH [3]. The frequency output shows ±2% %RH level accuracy. This sensing micro-system was successfully tested up to 150 °C.

The SOI lateral PIN diode in Figure 1 can be used as an efficient photodetector. Photo-generated carriers in the intrinsic (I) region can be quickly separated by the lateral electric field and collected efficiently. As the ∼5 µm thick membrane is transparent to light wavelengths above 450 nm, optical reflection from the gold finish layer of the device package, acting as a bottom mirror, occurs and creates cavity resonance in the multilayer stack improving light absorption in the on-membrane SOI PIN diode for specific wavelengths.

Experimental responsivities of the on-membrane photodiodes at room temperature (RT) are 0.02-0.06 A/W within the visible and near IR light range in Figure 3, under -2.0 V reverse bias. Up to 2.5 × responsivity improvement has been achieved with regards to the diodes on the substrate [4]. Furthermore the responsivities of both on-membrane and on-substrate diodes increase with intrinsic length ($L_i = 5, 10, 20 \mu m$), as the percentage of device photo-sensitive area increases with $L_i$.

When temperature increases, the photodiodes can work stably from RT up to 200 °C, with a slight ∼5-15 % decrease of responsivity at 200 °C which specifically depends on the device (on membrane or substrate) and intrinsic length $L_i$ (5, 10, 20 µm).

References


[2] EU Innovation Award Winner in the area of “Micro/Nano Electronics” and “Smart System Integration” for FP7 SOIHITS project.


Abstract — CIGS and CZTS are promising materials in photovoltaic (PV) technologies thanks to their direct band gap and high absorption properties. The main efforts of our research group are focused on the understanding of interface-electronic recombination and its impact on the PV cell performance. To do this, advanced opto-electrical characterization techniques were successfully employed to extract the electronic properties of materials and devices. Additionally, SCAPS simulation models provide deeper understanding of the device physics and also serve as a predictive tool for further optimization.

Among all thin-film (TF) technologies, photovoltaic (PV) cells based on copper indium gallium diselenide (CIGS) absorbers yield the highest efficiency (>22%). Current approaches and future priorities within the CIGS TF PV community are focused on CIGS thickness reduction to further lower material costs and surface passivation concepts to reduce the electronic recombination at interfaces and further enhance the solar cell performance. These approaches involve novel methods to passivate the front and rear surfaces of the CIGS absorber by implementing (i) alkali post-deposition treatments at the front surface and (ii) rear surface field-effect passivation using gallium grading schemes within the CIGS absorber layer.

However, above-mentioned surface passivation approaches have been shown less effective when considering ultra-thin (<400nm) absorber layers. Hence, as an attempt to address these challenges, our research is focused on the “Rear surface passivated ultra-thin CIGS solar cell architectures” (i.e. PercIGS), notably by introducing an aluminum oxide passivation layer at the CIGS/Mo-back contact interface. More specifically our research, in collaboration with Upsala University and IMEC, aimed at the interface of material and electronic properties with a focus on novel cell technologies and architectures for next generation TF solar cells. A first major achievement resulted in significantly enhanced cell performance (by 4.5% in absolute values) on ultra-thin (<400nm) CIGS absorber layers, i.e. a reduced CIGS absorber usage (by 5-6 times) compared to the conventional CIGS thickness (>2μm) [1]. Additionally, in-depth analyses on the materials and devices were carried out using advanced opto-electrical and material characterization techniques to understand, correlate and optimize these properties towards stable, efficient solar cells [2,3]. Lastly, to generalize these electronic and interface passivation effects on the CIGS solar cell performance, a simulation model has been developed using Solar Cell Capacitance Simulator (SCAPS) TF PV software [4]. Future research priorities include: (a) to develop 2-D simulation model addressing the rear surface passivation effects, (b) rear-point-contact pitch optimization and (c) to develop Cd-free CIGS PV cells.

Another promising semiconductor material which responds to the requests of using only low-cost, non-toxic and earth-abundant elements is Cu₂ZnSnS₄ (CZTS). It is very close by its nature to CIGS, but not fully understood yet. This explains the motivation to CZTS absorber layer as well for full device studies. Moreover, in frame of collaboration with AC&SC research center, the application of steel is proposed as flexible substrate, which introduces some new specific problems, but open doors on a huge market. The aim of our research is to understand the physical phenomena occurring in a CZTS cell built on a steel substrate. The main present focus is on the Mo-back contact/absorber interface problem. To study this, modeling and simulation are performed as well as full opto-electrical characterization, not only of the completed cells, but also on specific test structures like TLM and MIS as well.

These research activities were performed at ICTEAM, within the frame of the “CZTS Region Wallon” project.

References

Adaptive Li-ion battery management systems

Keywords: Hybrid Li-ion battery; Power management; Reconfigurable architecture.

Ionel Avram, Alexandru Vlad, Georgiana Sandu, Sorin Melinte

Abstract – We develop a new class of hybrid Li-ion batteries, displaying unique energy and power characteristics for mobile and stationary energy applications. Additionally, an adaptive battery management system [BMS] is under scrutiny and aims to improve the power conversion efficiency, safety, reliability and maintenance cost compared with conventional electrochemical energy storage systems. At the heart of the developed BMS there is a unique switching matrix providing selective connection, isolation and protection to the multi-cell battery pack. In particular, it allows cells to be connected in specific configurations providing the maximum energy, the maximum power or a balanced energy/power output. Our study applies adaptive reconfiguration principles to novel Li-ion battery chemistries and architectures.

Application-driven supercapacitors, Li-ion cells and battery packs are complex electrochemical devices [1,2], and developing technologies to cost-effectively monitor and manage important performance parameters, while precisely predicting product life, is a key challenge (Fig. 1).

An efficient battery management system ensures electrical safety during operation, while increasing battery lifetime, capacity and thermal stability. Conventional BMSs are designed to accommodate stacked multi-cell battery topologies. This approach offers limited safety, reliability, power conversion efficiency and maintenance costs.

To solve these issues, a reconfigurable battery architecture strategy is employed for the deployment of hybrid supercapacitors/Li-ion batteries in realistic environments. A reconfigurable architecture applied to micro-scale batteries was introduced recently [3]. We propose a different topology using the minimum number of switches in order to achieve the maximum flexibility in terms of voltage and capacity. A first prototype was built in order to evaluate the performance and feasibility of such system (Fig. 2) for scalable, stationary energy storage.

The proposed adaptive battery management system evaluates physical internal states of the Li-ion batteries (especially hybrid supercapacitors/Li-ion batteries [1]) fast and accurate, enabling thus the measured data to be useful in making decisions about how to control and optimize the battery packs in real time. Based on the current battery pack status and the load demand, the system will select the optimal cell configuration to maximize the battery capacity over time and minimize system power consumption.

The core of the adaptive battery management system is a Field Programmable Gate Array [FPGA] and a Real Time Operating System [RTOS] in order to manage the battery modeling algorithms and the configurability of the battery pack. In its current version, the system can manage four cells and can be upgraded to work with more cells by using more modules.

Through an adaptive reconfiguration algorithm, the BMS can isolate the faulty or damaged cells from the battery pack in order to enhance the battery dependability and safety.

In conclusion, we proposed an adaptive battery management system that can change its internal topology in order to deliver the maximum voltage, the maximum capacity or a balanced power/energy output. The goal of this technology is the development of intelligent Li-ion cells and hybrid supercapacitor/Li-ion batteries in tandem with battery management systems using novel control techniques and modeling software to decide how high power/high energy modules are connected, charged and discharged in the battery pack.

References

Trap-rich substrate enabling the RF Silicon-on-Insulator integration in all smartphones

Keywords : Silicon-on-insulator (SOI); RF; High frequency characterization; Substrate losses; Crosstalk; Non-linearity; Telecommunication device.

Jean-Pierre Raskin, Dimitri Lederer, César Roda Neve, Khaled Ben Ali, Babak Kazemi, Martin Rack

Abstract – Silicon substrate losses and non-linearities were the limiting characteristics of Si-based MOSFET technologies to provide low-power and low-cost solutions to the mobile RF device market. Thanks to the trap-rich Silicon-on-Insulator (SOI) substrate invented at UCL and developed in collaboration with the French company SOITEC, RF SOI is becoming a mainstream technology which is implemented in all mobile devices today.

Silicon-based MOS technologies have been considered as a potential candidate for providing an efficient and cheap solution for RF mobile devices since the 1990’s. The cutoff frequency of MOS transistors has been greatly increasing in the last decade due to the shrinking of the transistor channel size (the downscaling driven by the digital applications - Moore’s law). However, substrate losses and crosstalk remained the killer feature of Si-based technologies for RF Front End Module (FEM) applications.

In 1997, Prof. J.-P. Raskin presented pioneering work on the RF performance of high-resistivity (HR) Silicon-on-Insulator (SOI) substrate material. The great potential of HR SOI substrate to reduce RF losses as well as the crosstalk in Si-based substrates was demonstrated [1]. Prior to this work, the scientific community considered the Si-based substrate as the limiting and blocking obstacle for working RF Front End Module ICs. In 2005, Prof. J.-P. Raskin’s group presented the possibility of creating HR SOI substrates characterized with an effective resistivity as high as 10 kΩ·cm due to the silicon surface modification below the buried oxide (BOX) of a high resistivity SOI substrate [2]. The surface modification consists of the introduction of a high density of defects called traps at the BOX / HR-Si handle substrate. Those traps originate from the grain boundaries in a thin (300 nm-thick) polysilicon layer (Fig. 1). This high-resistivity characteristic, which is conserved after a full CMOS process, translates to very low RF insertion loss (< 0.1 dB/mm at 1 GHz) along coplanar waveguide (CPW) transmission lines and purely capacitive crosstalk similarly to quartz substrate [3]. It has been demonstrated that the presence of a trapping layer does not alter the DC or RF behavior of SOI MOS transistors [4]. Besides the insertion loss issue along interconnect lines, the generation of harmonics in the Si-based substrates has been investigated. We demonstrated that the harmonic level originating from the substrate is reduced (Fig. 2) by at least 20 dB by moving from standard resistivity SOI substrates (∼100 Ω·cm) to high resistivity SOI (∼1 kΩ·cm), and more importantly, an additional drop of 40 dB is achieved with the innovative trap-rich HR SOI substrate [5]. This low harmonic level is comparable with insulating substrates. This discovery has led to two patents. Since 2009, Prof. Raskin’s group has been collaborating with SOITEC (a company) to develop a lossless SOI substrate for RF applications. Due to the introduction of an engineered SOI substrate based on Prof. Raskin’s discovery, SOITEC now provides a new type of HR/SOI called eSi™, for RF enhanced Signal Integrity substrate with a measured effective resistivity as high as 10 kΩ·cm. Thanks to the introduction of eSi, the RF SOI substrate can really be considered as a lossless Si-based substrate. Beyond the RF switch (Fig. 3), eSi RF-SOI technology opens the path for further system integration in the Front End Module space as well as even more complex mixed signal System-on-Chip (SoC).

References

Lab on-chip for testing thin film materials: extraction of mechanical properties and coupled effects at the nanometer scale

Keywords : Thin films; Internal stress; Nanomechanical testing.

Michaël Coulombier, Audrey Favache, Mohamed Hammad, Hosni Idrissi, Guerric Lemoine, Romain Tuyaerts, Ferran Ureña, Astrid Van der Rest, Jean-Pierre Raskin, Thomas Pardoen

Abstract – Thin films constitute the building blocks of a large number of modern technologies including protective coatings, microelectronic devices, bio-responsive membranes and photovoltaic cells. These nano-layers exhibit vastly different mechanical properties from their bulk counterpart. In this context, a lab-on-chip technique has been developed to extract the mechanical properties of thin films.

From a collaboration between Prof. Raskin (ICTEAM) and Prof. Pardoen (iMMC), a simple lab-on-chip concept has been created to assess the mechanical properties of submicron freestanding thin films [7]. It relies on the use of internal stresses generated in an "actuator layer" to apply a deformation to a "specimen layer" attached to it owing to the release of an underneath "sacrificial layer" (see Fig. 1). The simplest test structure configuration gives access to one point of the stress - strain curve of the specimen material while photolithography enables to reproduce this elementary tensile test structure thousands of times to generate the full stress - strain behaviour up to fracture.

This simple idea gives access to several extensions:

- The loading configuration can be changed by modifying the geometry of actuator and specimen beams;
- Relaxation tests can be performed by monitoring the displacement versus time of test structures;
- The deformation mechanisms can be observed by transmission electron microscopy. This requires an additional process step known as back-etching of the silicon substrate which consists in opening a cavity underneath the freestanding structures (see Fig. 2a);
- Electromechanical measurement can be performed by changing the specimen into a loop-shaped structure with isolated pads for electrical contacts. This enables to measure the piezoresistance of the specimen material (see Fig. 2b);
- The test structures can easily be stored under various environmental conditions (temperature, moisture, gas, irradiation, etc.) before release to determine the impact on properties or after release to see the impact on relaxation. The "authors" line at the top of the page is meant to mention all implied researchers, not only primary investigators. If possible, add a hyperlink for each

This lab-on-chip concept has already proven to be suitable for extraction of mechanical properties of ductile materials (Pd [7], AlSi, Ni, Cu, Pt, etc.) as well as brittle materials (monocrystalline Si, polycrystalline Si, oxides, nitrides, metallic glasses). The piezoresistance of silicon nanowires under high tensile stress has also been assessed through this technique [7].

References

Scientific Highlights 2016

Antennas: numerical methods and systems

Keywords: Integral equations; Beamforming systems; Metamaterials.

Maxime Drouget, Donia Oueslati, Khaldoun Alkhalifeh, Christopher Raucy, Simon Hubert, Denis Tihon, Sumit Karki, Quentin Gueuning, Ha Bui Van, Inès Adouani, Julien Lambert, Thomas Pairon, Husnain Ali Kayani, Modeste Bodehou, Christophe Craeye

Abstract – UCL’s Antenna Group is active in the field of fast integral-equation methods for the analysis of antenna arrays and metamaterials. The Groups also realized a number of demonstrators centered on multiple-antenna systems, devoted to direction-finding and near-field imaging.

The Antenna Group at UCL/ICTEAM conducts research in the fields of numerical analysis and design of multiple-antenna systems.

From the analysis point of view, the methods under development are relying on an integral-equation approach, for which the unknowns are limited to interfaces. This is made possible thanks to the exploitation of a vast set of analytical results. For array problems, including metamaterials¹, accelerations by several orders of magnitude have been made possible through the use of “Macro basis functions”, FFT-based convolutions, multipole decompositions, complex-plane analysis, Green’s function compression, etc.

From the system point of view, a number of demonstrators have been developed for direction-finding and near-field imaging, in close collaboration from industry. Those systems also include the micro-wave front-ends and base-band conversion, and in some cases, the array signal processing.

The applications currently under study are the following:

- Chipless passive RFID (with Profs. Aguili and Rmili)
- Analysis of particle’s accelerators (with SCK-CEN and Prof. Remacle)
- Ground penetrating radar (with Prof. Lambot)
- Reflect-arrays and frequency-selective surfaces
- Centimeter-wave radar (with Profs. Vanhoenacker and Vandendorpe, and Dr. Razavi Ghods)
- Arrays devoted to radio-astronomy (with Dr. de Lera Acedo and Dr. Razavi Ghods)
- Metamaterials for THz sensing (with Prof. Withington)
- Beamforming with transponder on Mars (with Prof. Dehant)
- Ultra-wideband positioning (with Profs. Vandendorpe and Flandre)
- Real-time polarimetric RFID tracking
- High-gain metamaterial antennas
- Urban propagation (with Prof. Oestges)
- Acoustic brain stimulation (with Prof. Moureaux)
- Beam-scanning antennas (with Prof. Huynen)
- UWB near-field imaging (with Prof. Rmili)
- Scattering by moving objects (with Prof. Oestges)
- Small antennas for wireless maintenance
- Phased arrays for 5G communications.

References


¹Metamaterials are periodically structured material engineered to exhibit unusual electromagnetic properties.
Radio channel characterization and modeling for vehicular communications

Keywords: Radio propagation; Wireless communications

Olivier Renaudin, Rui He, Claude Oestges

Abstract – Vehicle-to-vehicle transmissions have emerged as a key component of future communication standards, whose design and testing critically depends upon the understanding of propagation mechanisms. An important and specific aspect of vehicular communication channels lies in the fact that these are essentially non-stationary. Hence, this short paper addresses two recent contributions in the field of non-stationary vehicular propagation, based on extensive measurements conducted at 5.3 GHz in suburban, urban, and underground parking areas.

Vehicular wireless channel modeling has received significant attention in the last decade in the context of Intelligent Transportation Systems (ITS). In addition to multimedia communications, ITS should further enable all vehicles to collect traffic data and road state information and share information for safety improvements thereby preventing road accidents by periodically monitoring the locations of surrounding vehicles. Naturally, this should be paired with a dependable connectivity, as such applications imply strict packet delay constraints. The system performance is ultimately fixed by the propagation channel, which must therefore be modeled accurately.

However, because both transmit and receive terminals are possibly moving, sometimes at high speeds, vehicular propagation is characterized by non-stationary conditions, making classical cellular models inadequate on this point of view. The first issue to be addressed is thus to define the so-called quasi-stationary region, i.e. the finite region in time or space over which the channel statistics remain similar enough. Of course, appropriate similarity measures are required to substantiate what “similar enough” means. Once stationarity regions have been identified, the second issue is to model the wireless channel, taking into account the non-stationarity aspects, in particular the transitions between successive stationarity regions. Both issues have been addressed recently, based on numerous measurement campaigns and modeling efforts.

The measurement campaign used the Aalto MIMO channel sounder [1] at 5.3 GHz and a bandwidth of 60 MHz and a transmit power of 36 dBm. The receive terminal was equipped with a dual-polarized semi-spherical antenna array comprising 15 dual-polarized patch elements (i.e. 30 feeds). A uniform linear array with 4 vertically polarized semi-spherical antenna array comprising 15 dual-polarized omnidirectional antenna elements was used at the transmit side. Both antenna arrays were mounted on wooden platforms atop the roof of two cars. These cars were driven at 5 to 40 km/h into four environments: Aalto university campus (Otaniemi), the suburbs and city center of Tapiola and an underground parking lot. The inter-vehicle distance varied between 10 and 500 m, depending on the traffic conditions, which ranged from no traffic at all (in the underground parking area) to heavy (in urban and suburban areas), with frequent obstructions of the line-of-sight. A detailed overview of the full setup can be found in [2, 3].

When dealing with quasi-stationarity concepts, it is important to make a distinction between the propagation level and the system level. The former can be thought of as the inherent non-stationarity of the physical propagation channel, as determined by the dynamic multipath components. Naturally, it should be independent of the system configuration. The latter results from the combination of the channel with the system resolution in delay and angle. Hence, it depends on the bandwidth and on the antenna array size and reflects the characteristics that the system can “see”. For a system with infinite bandwidth and perfect angular resolution, the quasi-stationarity on system-level tends to the propagation-level quasi-stationarity. This implies that the estimated degree of non-stationarity reduces when the bandwidth and array size become limited [3].

The second axis deals with channel modeling: the proposed non-stationary vehicular channel model [4] is essentially a stochastic directional tap-delay line model. The most important aspect of the model is the smooth transition from one region to the next one, which rests essentially on a birth-survival-and-death process for each multipath component (MPC).

This model has been successfully validated by experimental data in [4], as illustrated below.

![Figure 1: Comparison of measured (left) and simulated (right) power delay and power-angular profiles in suburban environments.](image-url)

References


Radio channel dynamics for wireless body area networks

Keywords: Radio propagation; Wireless communications; Biomedical sensors.

Evgeni Vinogradov, Claude Oestges

Abstract – Recent results about body area radio channel dynamics are analyzed, considering on-body and body-to-body transmissions. Investigations are based on experimental data around 4 GHz. Regarding the on-body case, the dynamics of cross-channel correlation are measured and analyzed for stationary periodic and non-stationary motions, with a clear impact of the walking mode being observed. For body-to-body scenarios, measurements conducted in room-to-room environments show again some strong non-stationary behaviors. In both cases, Markov chain-based models are developed to represent transitions between fading states.

Wireless Body Area Networks (WBANs) typically consist of transceiver nodes placed on or in the vicinity of the human body and encompass a large number of applications, such as e-health, remote monitoring, sports and entertainment. Understanding the radio channel behavior is critical to develop efficient body-area communications systems, especially when relay and cooperative techniques are considered to overcome the severity of on-body path-loss and/or body shadowing. In particular, the prediction and modeling of channel dynamics may strongly differ from classical wireless transmissions.

In a first part, we characterize the Doppler spectra for on-body channels with transmit and receive sensors located on the torso [1, 2], the transmission being impacted by the regular motion of the arms. In this case, the Doppler spectrum is very peaky around 0 Hz, as none of the nodes are moving with respect to each other, but exhibits strong harmonics resulting from the swinging of the arms. When the walking mode is non-regular, the channel becomes highly non-stationary. This implies first that the Doppler spectrum can only be defined over very short periods of time, but most importantly, that cross-channel correlation properties also change rapidly between successive stationary states. To illustrate this observation, let us compare two experimental results [3]. In both cases, one is interested in the correlation between two links, from the chest to the right hand (CRH) to the left hand (CLH) respectively. In the first measurement setup, the subject walked uniformly along a straight line with periodic arm swing, whereas in the second setup, the trajectory and the arm swings were completely random, likely representing a more realistic type of walk. In the first scenario, Fig. 1 (top) highlights that both links exhibit strongly anti-correlated fading behaviors. This is the direct consequence of the regular (soldier-like) swinging of the arms. This pattern is expected to result in high anti-correlation values that could be exploited in multi-hop approaches. By contrast, the bottom graph shows that the correlation behavior varies strongly over time in the second set of measurements.

The second part deals with body-to-body communications, which are emerging as a key component of future 5G networks. Most studies usually assume that the channel is stationary: while this is justified in some cases by the careful choice of experimental scenarios, it is likely that typical body motion and shadowing will induce non-stationary conditions. In [4], a body-to-body measurement campaign was carried out in two environments: subjects were either grouped in a large room or isolated in different rooms. In both cases, they moved freely on their own, avoiding regular motions. The experimental set-up relied on the UCL PropSound MIMO channel sounder, used in a distributed fashion at the frequency of 3.8 GHz. The distributed body nodes were connected to the sounder by long cables. Based on this experimental campaign, small-scale fading was found to strongly differ from one stationarity period to the next one, and its distribution ranged from double-Rayleigh to highly Ricean.

Figure 1: Comparison of correlation behaviors for two links and two walks: regular (top) and non-regular (bottom).

References

Modelling of tropospheric channel degradations on earth-space propagation

Keywords: Radiowave propagation; Millimeter wave; Troposphere; Ionosphere.

Danielle Vanhoenacker-Janvier, Alberto Graziani, Carlos Pereira

Abstract – Telecommunication, Navigation and Earth Observation systems used worldwide, have space segments operating in various frequency bands. The impairments due to the propagation of electromagnetic waves need to be evaluated accurately since system performances and sensitivity increase. The RAPIDS II software proposes a web interface to calculate the effects of the troposphere, ionosphere and environment, but also the potential interferences coming from nearby stations. The user can either use the default ITU-R Recommendation models and datasets or enter his own datasets for comparison. Examples are shown to highlight the versatility of the tool.

RAPIDS II allows registered users to log-in, via Internet, and to perform propagation calculations. A novelty of this version is that it is addressed to system engineers, via generic systems, as well as propagation experts. The output is in the form of statistical curves or time series for tropospheric attenuation, scintillation and environment. Output files are in HDF5, MATLAB and CSV formats.

The system workflows have 3 generic systems:
- Fixed Terminal Telecommunication System;
- Mobile Terminal Telecommunication System;
- GNSS.

For each system, a limited subset of effects is proposed by default. If the user chooses the Fixed Terminal TLC System, he chooses the satellite orbit, the atmospheric layer (Tropospheric effects ($f > 3$ GHz) or Ionospheric effects ($f < 3$ GHz) and the type of satellite coverage (Single Earth-station or Region). If non-GEO satellites are chosen, only Single Earth-station is available. In very specific cases where both tropospheric and ionospheric effects are needed (for example in tropical areas), the user runs the software twice, once for each layer. The advantage is that he can store its configuration in "My calculation" and recover the stations or region and satellite for the second run. The models proposed are the default ITU-R models and data.

For the Mobile Terminal TLC system, three impairments are proposed: Environment effects, Tropospheric effects and Ionospheric effects.

Only Environment effects and ionospheric effects are available for GNSS system. In the two last systems, the mean position of the mobile receiver is requested.

The expert user mode gives access to the full choice of effects, models and data, with a total of 7 different workflows.

- Ionosphere (satellite mode)
- Troposphere
  - satellite mode
  - single site mode
- Rain fields or tropospheric time series
- Environment (satellite mode)
- Interferences
  - Transmission loss
  - Coordination area

Figure 1: Screen presenting the generic systems.

In any workflow, the user chooses the effect to compute and the model that will perform the calculation. Fig. 2 shows the attenuation due to water vapor in Europe, exceeded for 0.1% of time.

Figure 2: Attenuation due to water vapor for Europe.

Fig. 3 illustrates the generation of rain fields over a region of 150 km by 150 km.

RAPIDS II has been delivered to European Space Agency and an access can be asked to esa.antonio.martelucci@esa.int.

Acknowledgement
This work has been performed under ESA contract 40000100892 “Propagation Analysis Tool for Design of Fixed and Mobile Multimedia”.

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Simulation of tropospheric total attenuation based on numerical weather forecast simulations

Keywords: Tropospheric attenuation; Numerical weather forecast; Earth observation data downlink.

Laurent Quibus, Carlos Pereira, Danielle Vanhoenacker-Janvier

Abstract – Tropospheric total attenuation is well modelled for Earth to satellite communication in clear air and rainy conditions. Time series simulators have been developed for geostationary links but are not valid for spatial applications involving Low Earth Orbit (LEO) satellites such as Earth Observation Satellites. A new simulator is developed in order to take into account both the dynamic behaviour of the troposphere and the movement of the LEO satellite. This model takes advantages of the outputs generated by Weather Research and Forecasting software which simulates the space-time behaviour of the turbulent troposphere.

The necessity of increasing the data rate for new spatial applications forces the utilization of higher frequencies, such as Ka-band (26.5-40 GHz) and W band (76 GHz). At these frequencies however, the signal transmitted becomes more sensitive to the tropospheric impairments. Even in the absence of rain, the scintillation generated by tropospheric turbulences in the lower part of the atmosphere impacts significantly the performances of the systems for low elevation links.

The WRF simulator

The WRF simulator [1] provides high resolution reanalysis and weather forecast simulating the space-time variation of the troposphere, with as output vertical profiles of pressure, temperature, humidity, rain, wind speed, etc. These parameters obtained with a kilometric space resolution enable the evaluation of propagation effects as attenuations due to gases, cloud and rain [2]. The outputs of this simulator are also used to compute the refractive index and its constant structure parameter for the assessment of the turbulent intensity and the calculation of its effects on radio wave propagation. Figure 1 shows a vertical cut of the evolution of the specific content of water vapour from WRF.

The tropospheric scintillation modeling

The model for tropospheric scintillation has been developed; it is based on a space-time varying meteorological environment simulated by a Numerical Weather Research and Forecasting simulator (WRF). The atmospheric data are used to quantify the turbulence intensity (proportional to the structure constant of the refractive index of the medium C_n^2) and predict the scintillation properties. Figure 2 shows C_n^2 at 2000m, where its intensity is maximum for this time of the day.

Figure 2: Intensity of refractive index structure constant C_n^2 above Louvain-la-Neuve on 7/7/90 10 am from WRF simulator.

The azimuth and elevation of the satellite during its passage above the station is then calculated from its orbital parameters and the time evolution of the signal received by the ground station is simulated taking into account the movement of the satellite and the movement of the air masses, clouds and rain simulated by WRF. An example of time series of scintillation due to turbulence is shown in Figure 3.

Figure 3: Time series of scintillation simulated using WRF meteorological parameters.

The full attenuation model is under development for Earth-LEO links simulation and tropospheric degradation nowcasting.

References


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Synthetized tropospheric total attenuation time series for satellite-to-aeronautical links from L to W band

Keywords: Tropospheric attenuation; Aeronautical channel.

Alberto Graziani, Carlos Pereira, Alessandro Vergani, Danielle Vanhoenacker-Janvier

Abstract – The synthetized attenuation time series together with the Complementary Cumulative Distribution of attenuation values play a crucial role for the design and validation of communication systems. ITU-R recommendations propose different models to characterize the channels. The ITU-R P1853 recommendation proposes a methodology for the synthesis of attenuation time series for ground stations. Based on the combination of different recommendations and external models, a time series generator produces the total attenuation for airborne platforms. The synthetized time series includes the combination of platform movements in the three dimensions and in the microwave frequency range.

Satellite services for aeronautical communication are currently available for different purposes: from passenger entertainment to Air Traffic Management (ATM) [1]. For this purpose the characterization of the aircraft-to-space link is crucial to guarantee all the proposed services. Due to the limitation in space, weight and dimension in airborne systems, the channel characterization is crucial and several contributions have to be considered, such as: atmosphere, aircraft attitude and ground scattering [2]. During the flight, the propagation terms affect the communication channel with different impact. For this reason, only an accurate analysis based on simulated time series can provide precise simulations of the link budget.

The model developed focuses on the effect of the troposphere in the aeronautical-to-space link, proposing a combination of ITU-R recommendations developed mostly for a ground-to-space link and adapting them for aeronautical scenario. Models are defined to evaluate the tropospheric propagation taking into account the variability in both time and space domain [3]. The models require several ancillary information which are available in terms of databases based on long term observations and statistical representation.

Two main recommendations are used for the proposed model: the ITU-R P1853-1 [4] which defines models for the tropospheric total attenuation time series synthesis, and the ITU-R P2041 [5] which predicts the various propagation effects for planning airborne systems links.

As anticipated, the crucial aspect of the aeronautical-to-space channel model is the altitude dependence of the tropospheric effects. Considering a typical commercial aircraft flight, it results that most of the flight time is spent at altitudes above the troposphere where most of its effects are negligible, but during the phases of take-off, climb and then descend, approach and landing, the troposphere effects become crucial and relevant, in particular if adverse weather conditions are encountered.

The atmospheric tool is used to generate the time series based on real flight path of commercial aircrafts. In this analysis a European regional flight between Rome Fiumicino, Italy and Stockholm Arlanda, Sweden is used. The flight path coordinates and altitudes have been acquired from Flight Aware1.

The simulation time corresponds to the combination of all the flight time plus a few minutes on the ground at the beginning and at the end, to represent the taxiing on the ground at the two airports.

Figure 1: Simulation of time series of total attenuation encountered during a flight.

Fig.1 depicts the attenuation effects during the flight. The random generation of the input parameters of the time series generator results in a clear sky day in Rome and rainy conditions in Stockholm, with a strong combination of all the effects.

The model has been tested in various configurations, including a fixed position on earth in order to be validated with the classical earth-space links models.

In the frame of an ESA contract, this model is introduced in a full simulator of the aeronautical link, taking into account the attitude of the aircraft.

References


1Flight Aware web site : https://www.flightware.com/
Electromagnetic radar simulator for wind speed and wake vortices detection

Keywords: Wind radar simulator; Turbulence; Wake vortices detection.

Dmitry Kovalev, Matthieu Duponcheel, Philippe Billuart, Danielle Vanhoenacker-Janvier

Abstract – A new electromagnetic radar simulator has been developed by UCL in the frame of the FP7 UFO project aimed at improving the Wake-Vortex Advisory Systems by the analysis, design and development of innovative technologies for Ultra-Fast Radar and Lidar used as wind and Eddy Dissipation Rate sensors. Experimental trials have taken place at Toulouse airport giving access to concurrent collocated X-band radar data and meteorological data. Preliminary validation of the simulator has been performed against radar and meteorological values of Eddy Dissipation Rate, showing a reasonable agreement. The simulator has also been applied to the detection of wake vortices, in the presence and in the absence of rain.

The UFO FP7 project (Ultra Fast wind sensOrs) [1] was aimed at improving the Wake-Vortex Advisory Systems by the analysis, design and development of innovative technologies for Ultra-Fast Radar and Lidar used as wind and Eddy Dissipation Rate ($\varepsilon^{1/3}$) sensors. These sensors are used for Wake-Vortex hazards mitigation but also for wind sensing and more specifically cross-wind, air turbulence and wind-shear detection on runway for increasing the aviation safety and reducing the safety margin of wake vortex separation between aircrafts during landing and take-off. Experimental trials have taken place at Toulouse and Munich airports.

In the frame of the project, UCL has developed a radar electromagnetic simulator for RCS (radar cross-section), wind and EDR ($\varepsilon^{1/3}$) retrieval, in clear air and in the presence of rain. The simulator is based on refractive index calculated from Large Eddy Simulations (LES) of the turbulent atmosphere in the boundary layer, for selected values of $\varepsilon^{1/3}$ representing various turbulence intensity, and Brunt-Vaãŧala frequency (N) representing stratification levels. The refractivity is then used for the calculation of the radar cross-section of the turbulence as well as the power received by the radar and the Doppler spectrum.

Using the same X-band radar for the detection of the wake vortices and wind necessitates a careful analysis of the signal received by the radar in clear air due to its low value. The feasibility of using radar and Lidar for the detection of wake vortices and the determination of Eddy Dissipation Rate has been shown experimentally [2].

The Large Eddy Simulation software (LES) used in the UFO project provides realistic velocity, pressure, temperature and humidity fields to the electromagnetic simulator in order to simulate time series of the radar signal. It has been developed by De Visscher and Winckelmanns [3] for the study of the effect of turbulence on wake vortices. It has been extended to take into account the humidity transport and the presence of raindrops.

The electromagnetic field emitted by the radar is backscattered by irregularities of the atmosphere, more specifically eddies of the turbulent boundary layer. The Bragg scattering indicates that the radar is sensible to variations of the refractive index of the order of magnitude of half the radar wavelength. The model developed by UCL for the calculation of the backscattering of wake vortices has been extended to be applied to the wind intensity and direction detection.

The turbulent kinetic energy is estimated from the broadening of the Doppler spectrum and $\varepsilon^{1/3}$ is inferred from the turbulent kinetic energy. Various extraction methods have been compared during the project. Fig. 1 shows a comparison between the simulator, the Meteo-France data and the LATMOS CURIE radar data:

- the green dots represent $\varepsilon^{1/3}$ measured by LATMOS CURIE radar in ordinate and measured by Meteo-France in abscissa.
- the red and black + and x are the mean and mean ± standard deviation for the two “packets” of points.
- the red dots represent the values used as input for the LES simulations.
- the blue circles represent the simulated $\varepsilon^{1/3}$ extracted from the Doppler spectrum calculated with the time series simulated using LES at 1s, 30s and 60s of the LES simulation.

![Figure 1: Scatterplot of $\varepsilon^{1/3}$ measured by the LATMOS CURIE radard (ordinate) and issued from Meteo-France High Resolution Weather Forecast Model (abscissa) compared with the simulated $\varepsilon^{1/3}$ (blue circles) on April 10 2014, 9h-16h30.](image)

The underestimation of the $\varepsilon^{1/3}$ calculated by the simulator is further investigated.

For the first time an electromagnetic simulator based on LES simulation of turbulent atmosphere has been tested against radar measurements and meteorological data issued from High Resolution Weather Forecast Model. The next step will be the application of the simulator to wake vortices detection and the inclusion of raindrops.

References


Cell segmentation with random ferns and graph-cuts

Keywords: Cell tracking; Fluorescent microscopy; Random ferns; Graph-cuts.

Arnaud Browet, Christophe De Vleeschouwer, Laurent Jacques

Abstract – The progress in imaging techniques have allowed the study of various aspects of cellular mechanisms. To isolate individual cells in live imaging data, we introduce an elegant image segmentation framework that effectively extracts cells boundaries, even in the presence of poor edge details [1]. Our approach works in two stages. First, we estimate pixel interior/border/exterior class probabilities using random ferns. Then we use an energy minimization framework to compute boundaries whose localization is compliant with the pixel class probabilities. Once detected, cells can be tracked using multi-object tracking algorithms [2][3].

Progress in embryo culture and live imaging techniques has allowed direct observation of cellular rearrangements in embryos from various species, including those with internal development. The specific question addressed here is the cellular mechanisms of mesoderm migration during mouse embryo gastrulation.

As a preliminary step to cell movement analysis, our work focuses on cell detection and segmentation. The images collected using fluorescence microscopy exhibit many characteristics that make segmentation challenging. These include limited spatial resolution and contrast, resulting in poor membrane details. Moreover, the inner textures of distinct cells present quite similar statistics, making region-merging strategies inappropriate as long as they do not use edge information. To circumvent those limitations, we propose to adopt a two-stages approach. In an initial stage, we learn how interior pixels differ from background or border pixels. Then, we adopt a global energy minimization framework to assign cell-representative labels to pixels, based on their posterior interior/border/exterior class probabilities. Considering explicitly a class of pixels lying on borders between adjacent cells is critical since the main problem encountered by previous works on our dataset consists in splitting cellular aggregates into individual cells.

Formally, we use a semi-Naive Bayesian approach to estimate, in each pixel, the probabilities that this pixel lies inside a cell, on a boundary between adjacent cells, and in the background. We have chosen semi-Naive Bayesian estimation because it has been shown to be accurate and offer good robustness and generalization properties in many vision classification tasks. This last point is important since the manual definition of cell contour ground-truth is generally considered as a tedious task, which practically limits the number of available training samples.

Regarding the subsequent energy-minimization framework, we rely on the fast approximate minimization with label costs introduced by Delong et al. [4]. This global energy minimization framework is used to assign cell representative labels to pixels, based on their posterior interior/border/exterior class probabilities. We initialize the label set so that each cell is represented by at least one label. To do so, we extract a number of cell-representative seeds. In practice, each seed corresponds to the center of a connected set of pixels whose interior score lies above a threshold, as represented by red dots in Fig. 1. To circumvent the threshold selection issue, and to adapt the seed definition to the local image contrast, we consider a decreasing sequence of thresholds. Large thresholds result in small segments, that progressively grow and merge as the threshold decreases. Among those segments, we only keep the largest ones whose size remains (significantly) smaller than the expected cell size. This might result in multiple seeds per cell, as depicted in Fig.1. A unique label is then attached to each seed, adding one virtual label for the background. The fact that a single cell induces multiple seeds, and thus multiple labels, is not dramatic since the subsequent energy-minimization tends to filter redundant labels.

The right column in Fig.1 presents the segmentation resulting from our proposed ferns-based energy minimization. We observe that the regions extracted are in very good agreement with the ground truth depicted in the left column as dashed white line. In contrast to conventional algorithms (see [1] for a comparison), our segmentation procedure is able to accurately localize boundaries between touching cells. Moreover, our method is also able to merge multiple seeds within a unique region or to reject seeds situated in the background.

In final, our work appears to be an elegant, versatile and effective solution to exploit posterior interior/border/exterior probability maps in a segmentation context.

References

Multipath TCP

Keywords : Internet; Protocols.

Olivier Bonaventure, Sébastien Barré, Christoph Paasch, Gregory Detal, Fabien Duchêne, Benjamin Hesmans, Quentin De Coninck

Abstract – Multipath TCP is a recent TCP extension that supports reliable transmission of data over different communication channels simultaneously. Despite its recent standardization (January 2013), it has already been used to launch new services.

The Transmission Control Protocol (TCP) is one of the most important protocols on the Internet. It provides a reliable service on top of the unreliable network layer protocols (IPv4 and IPv6). TCP has evolved continuously since the first experiments in research networks in the 1980s. Still, one of the early design decisions of TCP continues to frustrate many users. TCP and IP are separate protocols, but the separation between the network and transport protocols is not complete. Each TCP connection is bound to the IP addresses used on the communicating hosts at connection-establishment time. As a consequence of this and despite the growing importance of mobile nodes such as smartphones and tablets, TCP connections cannot move from one IP address to another. When a laptop switches from Ethernet to Wi-Fi it obtains another IP address that cannot simply be used to continue existing connections.

Since 2008, ICTEAM researchers have participated to the design and standardization of Multipath TCP. Multipath TCP is a modern TCP extension that enables hosts to exchange data for a single connection over different interfaces or path. With Multipath TCP, a laptop that switches from Ethernet to Wi-Fi obtains another address and can still use it for the same connection. More precisely, Multipath TCP was designed with the following goals:

- It should be capable of using multiple network paths for a single connection.
- It must be able to use the available network paths at least as well as regular TCP, but without starving TCP.
- It must be as usable as regular TCP for existing applications.
- Enabling MPTCP must not prevent connectivity on a path where regular TCP works.

In addition to contributing to the design of the protocol, ICTEAM researchers have developed the reference implementation of Multipath TCP in the Linux kernel. The quality of this implementation has demonstrated that Multipath TCP is a viable protocol that can be deployed in today’s Internet. Our open-source implementation [2] has already been reused by several companies to deploy commercial services.

The Multipath TCP standard [1] was published by the Internet Engineering Task Force (IETF) in January 2013. In September 2013, Apple surprised the Internet community by deploying Multipath TCP on all its iPhones and iPads to support the Siri voice recognition application. Multipath TCP allows a seamless handover between WiFi and cellular networks for this application. There are now more than several hundred millions of Apple devices that use Multipath TCP, making it the fastest TCP extension to have ever been deployed.

This is not the only utilization of Multipath TCP on smartphones [4]. As already demonstrated by ICTEAM researchers in 2012, the open-source implementation of Multipath TCP can also efficiently be used on Android smartphones. This motivated Samsung and LG to port our open-source implementation on their smartphones. In Korea, Multipath TCP is used to provide higher bandwidth on smartphones by combining fast LTE and fast WiFi. Thanks to the work of ICTEAM researchers, Korean smartphones reach bandwidths of up to 1 Gbps.

Figure 1: Multipath TCP deployed on smartphones in Korea.

Another new use case for Multipath TCP combines fixed and mobile networks. In Europe, but also in Asia and America, governments push network operators to provide high bandwidth to all residential users. In large cities, high bandwidth can be offered by deploying optical fibers. However, in less densely populated areas, this is not sustainable from an economic viewpoint and operators wish to combine their fixed and mobile assets. This is the type of product that Tessares, a spinoff created by ICTEAM researchers, builds. Tessares installs Multipath TCP on DSL routers and uses it to efficiently combine DSL and LTE networks. Other companies such as intel, Ericsson, Swisscom, OVH or Nokia are also active in this market. Several of them also reuse the open-source implementation of Multipath TCP [2,3].

Figure 2: Multipath TCP used in Hybrid Access Networks.

Other use cases for Multipath TCP are still being developed both by researchers in the labs and by several companies. This success story demonstrates both the quality of the research conducted by ICTEAM researchers and the multiplicative effects that an open-source implementation brings.

References

Robust and scalable software defined networks

Keywords: Computer networks; Routing protocols.

Olivier Bonaventure, Renaud Hartert, David Lebrun, Pierre Schaus, Olivier Tilmans, Stefano Vissicchio

Abstract – Software Defined Networking (SDN) is a new paradigm in computer networks where network operators write or compose software tools to manage their network. SDN promotes better manageability by relying on a logically centralized controller that exposes high-level configuration interfaces and network abstractions. We describe our effort in developing SDN based on the Segment Routing architecture and the recently proposed Fibbing approach.

Managing enterprise and service provider networks is a hard task for operators, regularly resulting in outages and often hampering the deployment of new services. Despite their huge (economical and technical) impact, configuration errors causing large-scale outages, unexpected behaviour and sub-optimal performance are common and hard to prevent in current networks, especially ISPs. Indeed, ISP operators have to manage huge, geographically distributed networks and high traffic volumes. To this end, they must configure each of the thousand devices in their networks, using low-level, vendor-dependent and platform-specific languages.

Such configurations fine-tune the behaviour of distributed protocols, hence providing an indirect control on the final network behaviour. Even worse, to offer a competitive set of services to their customers, operators have to fine-tune a large number of subtly interacting protocols (from IGP to MPLS, BGP and often RSVP-TE, VPLS, etc.), which makes both configuration correctness and optimality hard to be guaranteed.

For ISPs, Software Defined Networking (SDN) represents a unique opportunity to mitigate all those concerns, by improving both manageability and flexibility. SDN promotes better manageability by relying on a logically centralized controller that exposes high-level configuration interfaces and network abstractions. For example, the centralized controller enables declarative network management, according to which the operators can express management objectives (the what) rather than the low-level device settings (the how). Also, SDN allows operators to easily deploy new services (without the need of yet another distributed protocol), by leveraging the possibility to arbitrarily program devices – a feature often referred to as data-plane programmability.

Unfortunately, naive SDN solutions hardly work for ISPs and their strict robustness and scalability requirements. Beyond being not yet mature, SDN indeed collapses the control-plane into a single logic element, the controller, which therefore tends to be a performance bottleneck and a single point of failure.

ICTEAM researchers are exploring two parallel directions to enable the realisation of Software Defined Networks that are both robust and scalable: Segment Routing [1,3] and Fibbing [7].

Segment Routing (SR) is a modern source routing technique currently being standardized [1,2] by commercial vendors and network operators through the IETF. Segment Routing enables to steer packets through an ordered list of instructions, which can be topological or service-based. These instructions are called segments. There are two types of topological segments: node segments and adjacency segments. The presence of a node segment means that the packet must be forwarded through a specific network node. Conversely, the presence of an adjacency segment means that the packet must be forwarded along a specific link. This type of segment is often local to the node on which the link is connected to. An additional type of segment, the service segment, which is local to a node, represents a service to apply to the packet. This type of segment is important in order to support Service Function Chaining. Two dataplanes for Segment Routing are currently being standardized: MPLS and IPv6 [2].

We believe that the IPv6 extension for Segment Routing has the highest potential in the long term since it can be used both on endhosts and on routers. The first open-source implementation of IPv6 Segment Routing in the Linux kernel is developed within ICTEAM [3]. ICTEAM researchers have also worked on the design, optimization algorithms and implementation of a controller for SR networks. The resulting DEFO controller [4,5,6] enables network operators to express their objectives in a high level language and automatically translates those requirements into SR paths to be installed in the network.

The second SDN approach being pursued by ICTEAM researchers consists in centrally controlling the output of distributed protocols. We called this approach Fibbing [7]. Fibbing allows network operators to influence the paths used for specific sources-destinations pairs in a network by injecting carefully chosen information in an underlying link-state routing protocol. Fibbing is both more effective and easier to deploy than Openflow and Segment Routing. Indeed, Fibbing is scalable and robust, since forwarding-entry computation and installation are kept distributed (despite the decisions of the routing paths is centralized). Moreover, Fibbing does not require any modification to the dataplane since it is fully compatible with existing protocols (e.g., OSPF): Hence, it can be deployed in existing networks without any hardware change. The paper that proposed Fibbing [8] received the best paper award at SIGCOMM, the most prestigious networking conference.

References
BRB: better batch scheduling to reduce tail latencies in distributed data stores

Waleed Reda, Lalith Suresh, Marco Canini, Sean Braithwaite

Abstract – A common pattern in the architectures of modern interactive web-services is that of large request fan-outs, where even a single end-user request (task) arriving at an application server triggers tens to thousands of data accesses (sub-tasks) to different stateful backend servers. The overall response time of each task is bottlenecked by the completion time of the slowest sub-task, making such workloads highly sensitive to the tail of latency distribution of the backend tier. To address such challenges, we present BetteR Batch (BRB), a system that carefully schedules requests in a decentralized and task-aware manner. In doing so, we improve performance predictability of data stores in the presence of large request fan-outs. We show via simulations that our proposed design improves latencies over the state-of-the-art by a factor of 2.

Introduction

Recent studies [1] showed that latency distributions in Web-scale systems exhibit long-tail behaviors where the 99th percentile latency can be more than one order of magnitude higher than the median latency. To make matters worse, modern applications are highly distributed. For instance, interactive web services involve parallelization and aggregation of responses across 10s-1000s of servers, all of which need to finish for an end-user request (e.g., a search query) to be considered complete.

There have been several proposals for achieving latency reduction and lowering the impact of skewed performance across backend servers. These include (i) duplicating or re-issuing requests, predicting stragglers, or trading off completeness for latency [1], (ii) policy-based resource allocation and admission control (with the objective of achieving fairness or satisfying SLOs) [2], and recently (iii) making use of adaptive load-balancing [3]. In this work, we present BetteR Batch (BRB), which complements the aforementioned approaches using task-aware scheduling — a method of scheduling tasks across stateful backend replica servers according to expected service time of the enclosed sub-tasks.

Task-aware Scheduling Algorithms

A key insight to reduce tail latencies is that a task’s response time depends on the last of its requests to complete. BRB is based on a class of algorithms for task-aware scheduling that exploit this fact. At a high-level, these algorithms run at the clients of the data store as follows. When receiving a task, clients subdivide it into a set of sub-tasks, one for each replica group; therefore, a sub-task contains all requests for a distinct replica group. Clients then determine the bottleneck sub-task based on the costliest sub-task and assign a priority to every request in the task. Then, the priority information is propagated to the servers, which based on this can decide what request to serve next. To this end, we have designed two simple yet effective priority assignment algorithms:

1. **EqualMax**: Requests are given the same priority as that of the bottleneck sub-task. The intuition is that tasks with shorter bottlenecks should be given precedence in order to minimize their makespan.

2. **UnifIncr**: Requests are ranked based on the difference between the cost of the bottleneck sub-task and their individual cost. In other words, this effectively delays non-urgent requests in favor of bottlenecking requests.

Preliminary Evaluation

We resort to simulation to evaluate the potential benefits of our proposal. We assess BRB’s latency reductions versus ideal as well as state-of-the-art approaches — in our case, C3 [3]. In an ideal case, referred to as model, servers utilize a work-pulling mechanism to fetch requests from a single global priority-based queue shared by all clients. However, such a model is unrealistic since it assumes perfect knowledge of global state. Hence, we develop a credits strategy where clients report their demands at measurement intervals and are assigned credits (i.e., shares of server capacity) proportionally to demands via a logically-centralized controller.

For our evaluation, we use a real workload gathered from SoundCloud comprised of 0.5 million tasks and then generate task inter-arrival times using a Poisson process where the mean rate is set to match 70% of system capacity. Figure 1 depicts the read latencies averaged across experiments for different percentiles. The standard deviation is not shown as it is largely negligible. As shown, the credits strategy is at most 38% of an ideal model across different simulation settings. In addition, BRB outperforms C3 across all percentiles for both EqualMax and UnifIncr and improves the latencies by up to a factor of 3 at the median and 95th percentiles and up to 2 times at the 99th percentile.

References


ez-Segway: decentralize for faster consistent updates

Keywords : Software-defined networking; Network update.

Thanh Dang Nguyen, Marco Chiesa, Marco Canini

Abstract – Recent research in Software-Defined Networking (SDN) introduced control plane mechanisms for updating the data plane while avoiding forwarding failures such as loops, black-holes or congestion. However, the update speed of these mechanisms suffers from latency between control and data plane as well as the overheads of centralized computation.

We propose ez-Segway, a mechanism that enables robust, decentralized network updates while still enforcing the desired endpoint policy and avoiding forwarding inconsistencies and congestion. In our architecture, the SDN controller only computes the intended network configuration and certain information needed to perform the update. This information is distributed to the switches, which use partial knowledge and direct message passing to efficiently schedule network update operations. Our evaluations via large scale simulations and a system prototype demonstrate that ez-Segway improves update performance by a factor of 2 and reduces message overhead by a factor of 3.

Many recent SDN systems have demonstrated the value of centrally controlling networks. We observe, like others before us [1, 3, 4, 6], that regardless of their goal, such systems operate by frequently updating the network configuration, either periodically or in reaction to events such as failures, load changes or policy changes. Updating network configuration is inherently challenging because it involves performing operations across different unsynchronized devices in multiple steps, each of which must be planned to avoid forwarding failures (e.g., loops, black-holes or congestion).

Previous works have proposed mechanisms to update the network while retaining certain consistency properties during the configuration changes. Reitblatt et al. [6] introduced the notion of “per-packet consistency”, wherein every packet traversing the network must be processed by either the initial or final network configuration, even throughout the updated process. Their update procedure stamps packets with version numbers and uses a 2-phase commit protocol. Unfortunately, this approach is onerous in terms of memory overhead because it requires both the old and new forwarding entries to be present at switches’ flowtables during the update. Moreover, 2-phase commit also delays the time at which the new configuration is used.

Consequently, others [3, 4] have explored different trade-offs between time, overhead, and update properties. And, per-packet consistency by itself does not admit reasoning about congestion. However, all these approaches have always commonly assumed that the SDN controller actively drives the update by (i) scheduling every step, (ii) sending rule to switches, and (iii) pausing to await ACK from switches. While, the switches just behave as remote passive nodes.

ez-Segway, decentralized network update. In contrast with prior methods, we investigate the prospect of delegating the responsibility of consistent updates to the switches. We first relax the per-packet consistency to a more general “endpoint policy” consistency, which specifies how packets should be processed by the network but not necessarily the exact path (e.g., a flow of packets must traverse a middlebox but the accurate path through the network is not relevant).

Based on this endpoint policy, we propose a distributed network update architecture wherein the controller is only responsible for computing the intended network configuration and pre-computing information needed by the switches to schedule network update operations. The actual update function is realized by the switches, which coordinate execution of an update for the entire network using the information received by the controller and direct message passing. This allows every switch to update its local forwarding rules as soon as the update dependencies are met (i.e., when a rule can only be installed after dependent rules are installed at other switches), without any need to coordinate with the controller. We show this approach leads to faster network updates, reduces the number of exchanged messages in the network, has low complexity for the scheduling computation, and constitutes the basis for a new class of algorithms that perform planned updates while reacting to accurate data plane measurements and conditions (e.g., link congestion [2], connectivity failures [5]).

Our model allows us to relax per-packet consistency into a more general endpoint consistency, to solve potential unavoidable link congestion by carefully splitting traffic aggregates volumes, and to leverage “flow segmentation”, a novel technique to speed up the update of a single flow by parallelizing its update operations. Our results are as follows:

1. We design and implement ez-Segway, a system consisting of a reliable update scheduling mechanism that runs as software on switches, initially coordinated by a centralized SDN controller. Our algorithms enable decentralized network updates that preserve the endpoint policy while avoiding any forwarding failures and minimizing the risk of link congestion.

2. We assess our system by running a comprehensive set of emulations on various topologies and standard traffic patterns, which show that ez-Segway improves update time up to $2 \times$ and requires $3 \times$ less message overhead, and through extensive simulations, which also provide evidence of significant update time reductions for large scale networks up to $2 \times$. Further, we validate feasibility by running our system prototype on a real SDN switch and present microbenchmarks that demonstrate low computational overheads.

References


Abstract – One of the main challenges investigated for 5G wireless communication systems is the ability to take care of the largely increasing number of devices, establishing connections with a wide variety of requirements. Simultaneously, it is also crucial to fulfill the ever increasing demand of bit rate. The OFDM modulation (orthogonal frequency division multiplexing), used in most wireless communication systems today, forces the different devices to be synchronized in time in order to avoid interfering with each other. This might become an unaffordable burden when the number of devices and the number of cells increase. For this reason, FBMC (filter bank multicarrier) is being considered as a viable alternative. It simply separates the users in frequency and does not require any synchronization thanks to the low sidelobes of its filters. This project aims at studying the applicability of FBMC/OQAM for 5G, mainly focused on the study of the implementation of massive MIMO (systems using very large number of antennas) for FBMC/OQAM.

Orthogonal frequency division multiplexing (OFDM) is the most popular multicarrier modulation scheme nowadays. It is used for instance in systems such as WiFi, long term evolution (LTE, also known as 4G) or digital video broadcasting (DVB). OFDM has been very attractive mainly because of its low complexity of implementation. The introduction of the cyclic prefix (CP) in OFDM allows for easy channel equalization. Extension to multiple-input multiple-output (MIMO) scenarios is straightforward thanks to the OFDM orthogonality ensured in the complex domain. At the same time, due to the rectangular pulse shaping of the fast Fourier transform (FFT) filters, OFDM systems exhibit very high frequency leakage and poor stopband attenuation (see Figure 1). Furthermore, the use of the CP in OFDM significantly reduces the spectral efficiency of the system.

In the light of the shortcomings of OFDM, Offset-QAM-based filterbank multicarrier (FBMC/OQAM) modulation has been regarded as an attractive alternative. Rather than using a rectangle pulse in time, FBMC-OQAM uses a pulse shape which is more spread in time and has much larger stopband attenuation (see Figure 1). This in turn translates into higher spectral efficiency and relaxed synchronization constraints which allows the coexistence of large number of users in a very simple way. Moreover, it does not require CP overload, which allows for a larger spectral efficiency. The FBMC technique is already used in slightly different forms in some current standards (mainly in powerline communications) and has been investigated recently for several future applications such as cognitive radio (in particular in the Phydyas and Empathic European Projects). However, it has largely been ignored in wireless communications standards up to now due to the simplicity and efficiency of OFDM for these applications. Therefore, many issues appearing in nowadays wireless context have not been investigated in the specific case of FBMC and are only receiving attention very recently.

In this project, the applicability of FBMC/OQAM for 5G is studied. The project focuses, in particular, on the study of the implementation of massive MIMO (systems using very large number of antennas) for FBMC/OQAM. Due to the particular interference structure of this modulation, many issues related to massive MIMO need to be revisited such as the design of the precoding, or the channel estimation.

Regarding channel estimation in FBMC distributed MIMO systems, we have developed several algorithms aiming at allocating pilots to the different users while avoiding inter-user interference. The results prove that an unsynchronized FBMC/OQAM system might outperform a fully synchronized OFDM system in the considered scenario. Furthermore, classical FBMC-OQAM decoders are known to suffer from the frequency selectivity of the channel, especially in multi-users MIMO scenarios. The decoders that we optimized showed that the degradation caused by the channel selectivity might be easily and efficiently mitigated using extra antennas at the base station with a very low complexity of implementation (See Figure 2).

References


Abstract – In the Internet of Things (IoT), it is envisioned that a huge amount of physical objects will become online. From a security perspective, the more devices are connected to communication networks, the more powerful cyber-attacks can become. The goal of this research project is to design, develop and evaluate new distributed attack detection and mitigation approaches for the IoT.

Introduction. The number of interconnected devices already surpasses the number of connected people. This difference will become even larger with the Internet of Things (IoT) [1]. In the IoT, it is envisioned that a huge amount of physical objects, somehow capable of interconnecting to each other and to the Internet, will become online. From a user experience perspective, IoT will make life more comfortable by creating an interconnected environment, supporting daily tasks and decisions. From a security perspective, however, the more devices are connected to the Internet, the more powerful cyber-attacks can become. IoT devices can be attacked to cause damage to the physical appliances connected to them. Furthermore, IoT devices can be infected and become part of a botnet or be misused to perform distributed attacks, such as powerful Distributed Reflection DoS attacks. A first botnet with provisions for infecting IoT devices has been already identified [2].

Distributed Monitoring System. One way to prevent the misuse of networked devices is by monitoring the network’s incoming and outgoing traffic. A big challenge in securing the IoT in this way is its highly distributed character. As illustrated in Fig. 1, the IoT is not a monolithic structure but will soon consist of millions of local area and personal area networks (LANs and PANs) connected through border routers to the Internet infrastructure. Larger buildings will typically host several dozens of such LANs and PANs. Due to this distributed nature and the huge number of devices, we propose to monitor the networks’ incoming and outgoing traffic at the border routers to detect and mitigate incoming and outgoing attacks.

Another challenge is the cost of a potential solution. IoT devices are not expensive (down to a few cents) and end-users will not be willing to spend several hundreds or thousands of Euros to protect them. We envisage an intrusion detection system (IDS) that can be implemented in the border routers. Typically, such routers for (non-commercial) end users are cheap embedded devices, though more powerful than IoT devices. Our solution should work on two levels: On a local network level, an IDS instance will perform a preliminary analysis of the traffic to detect malicious activities. To be scalable in the presence of a massive DoS attack, our solution will mainly operate on flow level and not rely on deep packet inspection. The local network level will also provide input to a distributed collaborative level, which will be in charge of creating a consistent view on current threats. Such a collaborative approach will greatly increase the capability of the system to detect large-scale attacks and malfunctions, i.e., anomalous behavior that, although not suspicious and, hence, not detectable in an individual LAN or PAN, becomes visible when observed on a global scale.

Preliminary work. While network attacks against wired and WiFi networks have been extensively studied in the literature, there is, due to its young age, much less concrete information available on the characteristics of network attacks against the IoT. Furthermore, it is to a large extent unknown how complex IoT networks would behave in the presence of massive attacks.

Therefore, our first step has been to build ns3 models [3] to simulate networks in which IoT devices using different types of communication technologies are attacked. An example model is shown in Fig. 2, where an attacker attempts to perform a network scan from the Internet against an IoT infrastructure mixing WiFi and 6LoWPAN networks. The insights that we have gained from our simulations allow us to better understand potential attack strategies and to parameterize our envisaged detection methods.

References
Towards automatic configuration of big data processing systems

Abstract – The goal of this research is to develop a generic framework for automatic configuration optimization of big data processing systems. The framework will allow users to specify their performance goals as well as their own metrics. We plan on utilizing system developer provided hints for searching suitable configurations for big data application deployments.

Muhammad Bilal, Marco Canini

Introduction

Big data processing systems have dozens of available configuration parameters and system performance crucially depends on tuning several of these parameters. Moreover, the suitable configurations vary depending upon the available resources, workloads and applications for which the system is being used. Today, optimization of these configurations is done manually, possibly requiring several hours of investigation and testing by performance engineers. Performance engineers also need to have detailed knowledge about the big data system under consideration. This makes configuration optimization a tedious and time consuming task. Most of existing works present solutions specific to MapReduce jobs [2,3]. However, to the best of our knowledge the broader research challenge remains open.

Preliminary Analysis

To understand the variation in performance due to system configurations, we conducted preliminary tests on a multi-node Apache Storm cluster. The setup includes 3 nodes, with the capability to run 96 threads simultaneously. We use the Rolling word count topology of the Intel Storm benchmark [1], with count window size set to 10s and count emit frequency set to 1s.

Table 1 - Selected configurations and their values.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Possible values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of workers and acker threads</td>
<td>3-12 (each)</td>
</tr>
<tr>
<td>Spout, Split Bolt and Count bolt threads</td>
<td>3-64 (each)</td>
</tr>
</tbody>
</table>

Following an Experimental Design approach, we use a space filling algorithm to cover the configuration space. Table 1 shows the space of possible configurations considered for each experiment. We have fixed the total number of threads in the topology to 96. We vary the number of threads assigned to each of the topology component while keeping the total number of threads constant. We used the WSP space filling algorithm [4] to generate 77 configurations for our experiments.

Figure 1 shows the variation of different performance metrics across different configurations. The per-tuple latency varies between 3ms to 108ms at the median and from 3ms to 577ms at the 99th percentile. In addition, there is a substantial variation in throughput from 10k tuples/s to 117k tuples/s. Thus we observed a variation as high as 2 orders of magnitude in latency and 1 order of magnitude in throughput, given a fixed resource budget. The interplay between parallelism of different Storm components has lead to this drastic variance in performance. The amount of work done by each component of the topology and its processing latency, the number of executor for each bolt/spout and their placement, all play a part in the resulting overall performance.

Research Directions

In the current form our tool is able to provide recommendations for bolt parallelism configurations in Apache Storm, according to a performance metric. Two types of recommendations are made. First, a configuration that achieves the best observed performance. Secondly, a configuration that achieves performance within the tolerance level (specified by the user) of the first configuration while using less resources.

Beyond Storm, our goal is to design a generic framework that can be used and extended to provide automatic configuration for a large variety of big data frameworks. To achieve this, there are two main interface that need to defined and refined. An interface offered to the users of the framework and an interface for the system developers of the big data processing frameworks. The user interface should provide ways for the user to provide their own performance metrics as well as performance goals that can be transformed into a fitness function for the evaluation of different configurations. On the other hand, the interface for the system developer should provide information about the key configuration parameters, system-specific metrics APIs and performance metrics. We will use this information to automatically improve the application-specific configurations, instead of forcing users to understand the fine details about a big data system. Lastly, we plan on expanding the available search algorithms to incorporate evolutionary algorithms and other mechanism to give user a wide range of choices.

References

Abstract – The rapid evolution of smart mobile devices has triggered a growing need for context-aware software. Since the first appearance of context-aware applications in the early nineties, many applications on smart devices today are exhibiting context-aware features. This trend is likely to increase even further in future generations of software systems. Context-aware technology holds the key for software systems to offer the most appropriate behaviour to their users according to the current context of use.

Motivating example. Consider an advanced car dashboard system that provides various features, such as smart driving assistance for novice drivers. When localisation sensors, e.g. on a smartphone connected to the car, detect the car’s global position, the system may react by activating a location-specific module with, for example, country-specific driving assistance for driving on the left when in the UK. If the driving assistant for novice drivers would still be active as well, the country-specific assistant should seamlessly adapt to and integrate with the already active one.

Goal. While traditional software variability modeling approaches like feature modeling and software product lines are evolving to address the increased dynamicity and context specificity required for this new generation of software systems, new paradigms such as context-oriented programming [1-3] have emerged. Although developed independently, since they address similar issues, many similarities exist between these approaches. The purpose of this research is to combine the best of these approaches into a novel approach for managing context-aware software variability, to establish a shift from Software as a Service (SaaS) to Features on Demand [4], where small-grained software features can be added, removed or modified on demand, depending on the current context of use.

Features on Demand. In this novel programming methodology, as opposed to seeing applications as monolithic artefacts conceived for a single purpose, user, or context of use, we regard software applications as more dynamic “clouds of features” that are composed on the fly from sets of finer-grained features. Particular services are not pre-composed in a core system, but rather are dynamically composed from a set of available features, or adaptations of existing features, as long as they remain consistent with each other [5].

Figure 1: Composing applications from a “cloud of features”.

Approach. To achieve our goal, we rely on ideas from three different domains: feature modelling, software as a service, and context-oriented programming. Ideas from feature modelling and software variability management are used as a source of inspiration to model and represent features and contexts, as well as their intra- and interdependencies, and how to verify consistency of those models. Software as a service is the source of inspiration of our more fine-grained vision of features on demand. Thirdly, context-oriented programming [1-3] is used as implementation technology and to validate our solution, precisely because it supports the key properties needed for conceiving feature clouds: definition of fine-grained features describing new or adapted behaviour, the ability to associate these features with particular contexts of use, declaration of dependencies between features and contexts, and dynamic composition and activation of features depending on the context of use and declared dependencies.

Problems. From a scientific point of view, the four key problems that we investigate are:

1. an appropriate formalism and notation for representing and modeling features, the contexts on which they depend, and their intra- and interdependencies;
2. a formalism and semantics [5] for verifying both static and dynamic consistency of the feature and context models, to ensure a correct behaviour of the composed application;
3. a theory and algorithm for discovering the most appropriate features for a particular application, user or context of use;
4. a formalism and implementation of a composition mechanism allowing the definition of various composition policies and avoiding unexpected interactions between contexts and features upon composition.

Architectural components. Each of these four research problems match a key component in the architecture of our new development environment supporting our Features on Demand methodology:

1. a Feature Store offering a variety of features from which user applications can be built (or adapted);
2. a Feature Verifier which can be used to verify consistency between different features in the store or in an application;
3. a Feature Discoverer which gathers relevant information about the context of use and activates or deactivates desired features accordingly;
4. a Feature Manager which is aware of the different composition policies and interaction relations between contexts and features, and which takes these into account to guarantee that the system remains coherent and exhibits the desired behaviour.

References

Verification of railway interlocking systems

**Keywords**: Railway; Interlocking; Verification; Statistical model checking; Simulation.

**Quentin Cappart, Christophe Limbrée, Pierre Schaus**

**Abstract** – In the railway domain, an interlocking is the system ensuring a safe train traffic inside a station by controlling its active elements such as the switches or the signals. Modern interlockings are configured using particular data, called application data, reflecting the topology of the station and defining the actions that the interlocking can take. The safety of the train traffic relies thereby on application data correctness, errors inside them can cause safety issues such as derailments or collisions. However, the application data are nowadays prepared by tools that do not guarantee an intrinsic level of safety. Given the high level of safety required by such a system, verification of its data is a critical concern. We propose here a statistical model checking approach for verifying the application data correctness.

Until now, most of the research targeting the verification of the application data is based on model checking. First, the signaling principles and the application data are translated into a model. Secondly, the dangerous situations that the interlocking must avoid are translated into safety properties. Finally, a model checker tool unrolls the state space of the model and verifies that none of the reachable states violates the properties. The principle of verification is simple but suffers from the so-called state space explosion problem. In other words, the number of states is so big that its creation and exploration take exponential time. A different approach introduced by Cappart et al. [1] consists in performing the verification by a discrete event simulation. The idea is to simulate the behavior of an interlocking as described in its application data and to observe if any unwanted scenarios occur. Unlike model checking where all the states are considered, this approach only considers scenarios that can potentially happen in practice. However, this method does not provide enough guarantees that all the conflictual scenarios will be detected. We propose here an intermediate statistical model checking approach, offering both the advantages of model checking and simulation. Before performing the verification, we need to define what are exactly the situations that we want to avoid. An interlocking must ensure that it will cause no accident in the station. It is a safety requirement. It can be split into three properties:

- A track cannot have two trains on it at the same time in order to avoid collisions.
- A railway switch cannot move if there is a train on it otherwise it will derail.
- A railway switch must always be set on a position allowing trains to continue their path. Otherwise the trains will derail.

The data flow diagram presented on Figure 1 resumes our approach. All this process in entirely automated. Let us describe the different parts of this approach:

- **The translators**: they are used in order to build a model of an interlocking which can be verified thereafter. We designed two translators, one for the application data, describing the interlocking behaviour, and one for the track layout, reflecting the geographic topology of the station. Their output are then aggregated in order to construct the model.
- **The simulator**: it is used in order to simulate the interlocking model obtained from the translators. The key idea is to reproduce the interlocking behavior under a realistic train traffic. It gives as output a set of traces. Each of them represents the set of states reached by a particular simulation.
- **The statistical model checker**: it is used to verify that the model satisfies all the requirements stated. To do so, it performs several simulations, gets the resulting traces, analyses them and verifies that all of them contain no state violating the requirement. If there is at least one simulation that does not satisfy a requirement, we can deduce that the application data are incorrect.

The aim of statistical model checking is to approximate, in a controlled manner, the probability of satisfaction or violation of a property. To do so, two algorithms are used:

- **Monte Carlo**: the principle is to generate N random simulations and to compute how many of them satisfy the requirements. Furthermore, Chernoff bound can be used in order to determine the required number of simulations that must be performed to obtain a specific confidence interval. The simulation time can also be defined. In our experiments, we perform simulations of one day each.
- **Importance splitting**: it is used for increasing the probability of generating rare events (as collisions) in order to speed up the error detection by decreasing the number of simulations required to estimate the probability. It works by splitting the property that we want to verify into a sequence of subproperties easier to verify. Once a state satisfying a subproperty has been reached, it can be used as a new start for the next simulations.

In order to analyse the validity of our approach, we introduced several errors in the application data. All of them have been thoroughly detected with an execution less than three hours through 100 simulations of one day.

Automatic verification of interlocking systems is an active field of investigation in the railway domain. Up to now, most of the research dealing with this issue is based on model checking or on discrete event simulations. However, both of these approaches have drawbacks. On this paper, we proposed an intermediate approach based on statistical model checking that overcomes both issues. Furthermore, experimental results confirm the validity of this method.

**References**

Abstract – A paradigm shift is underway in the field of distributed computing systems. From data-center based computing, we are moving toward edge computing, i.e., pushing the computation toward the logical extreme of a network. The inherent unreliability and heterogeneity of edge networks introduce a crucial challenge for distributed systems as the size of the system grows. To survive in inhospitable environments such as edge networks, the system needs to have strong self healing properties. We make empirical studies of both the behavior and design of these systems in inhospitable environments. We define the concept of a reversible system, where the system’s functionality depends on the current environment and not on its history. By showing how to make a distributed system reversible, we prepare the way to build provably correct distributed systems for arbitrarily hostile environments.

Complex systems, such as large-scale distributed systems, consist of many interacting parts. Their behavior cannot be predicted in a straightforward way from the behavior of each part. They have many operating modes depending on their environment and what they are supposed to do. This has resulted in many problems when such systems are stressed beyond where their behavior is a straightforward extrapolation of the behavior of their parts. Applications running on such infrastructures break down when there are too many node or communication failures. Ideally, the application should survive with partial functionality during arbitrary system failures and recover its full functionality when the underlying system is restored. This is not just a fringe case: mobile and ad-hoc networks, for example, have this kind of failure. Even supposedly stable parts of the Internet have peaks of unstable behavior.

In order to design provably correct complex systems, it is required to understand the behavior of such systems in inhospitable environments. We define an inhospitable environment as one in which certain stress parameters, e.g., churn (i.e., the rate of node failure and replacement), network partition, and communication delay, can potentially reach high values and temporarily increase without bound. The goal is to build systems that are both predictable (hence, useful in practice) and reversible (hence, they survive) in these environments. We say a system is reversible if it regains its original functionality as the stress recedes. Formally, reversibility means that the system’s functionality depends only on the current stress and not on its history.

An in-depth study of a complex system in its entire operating space is important for three reasons. First, for practical system design it is important to explore highly stressful environments, since even systems running in so-called “stable” environments also have peaks of high stress. Second, it can open new venues for application design, such as mobile, ad-hoc networks, Internet of Things (IoT), and general edge computing. All these have high node dynamicity and intermittent connectivity, and frequently change network topology. For them, current fault-tolerance techniques are insufficient. Third, it is important for scientific reasons to understand what happens in highly inhospitable regimes.

For our practical study, we have chosen a class of structured overlay networks (SONs) as our representative complex systems. SONs are the third generation of peer-to-peer systems (i.e., where each node of the system is both client and server), where a structure is induced through pointers maintained by each peer of the system. SONs are a well-known approach to building decentralized distributed systems. We extend the SON architecture to make it reversible. This can be achieved by carefully designing the maintenance strategies of the SON. A maintenance strategy actively maintains the structural integrity of a SON under certain environmental stresses. We organize the maintenance strategies proposed in existing literature along a spectrum between efficiency on one side and resilience on the other.

In order to describe the qualitative behavior of a SON, we introduce the concept of phase. Based on the concept of phase in physical systems [2], we have drawn an analogy for a SON. All nodes in the same phase exhibit the same qualitative properties, which are different for nodes in different phases. We demonstrate the existence of phase transitions (i.e., a significant fraction of nodes changes phase) as the stress in operating environment varies. We empirically identify the critical points (i.e., when there exists more than one phase simultaneously in significant fractions of the system) observed in our experiments. We propose an API to communicate the current phase of a node to the application layer. Our results show the usefulness of reversibility for designing a SON and of phase for building applications on a SON.

References


Keywords: Graphical user interface (GUI); Distributed system; DUI; Distribution graph.

Jérémie Melchior, Jean Vanderdonckt, Peter Van Roy

Abstract—The days when the desktop computer was the only computing device used by one single user at a time are over. Nowadays, one or more users share information across several devices, not only computers but also smartphones and tablets. In this document we describe how developers and users can handle this new situation.

Our goal is to provide a toolkit, called JayTk, for developers to create and manage Dynamic Distributed Graphical User Interfaces (DDGUIs) which is based on the concept of a Distributed User Interface (DUI). Distributed User Interfaces enable end users to distribute any user interface element at design- and/or run-time across different users, across different computing platforms, and across different physical environments. A Dynamic Distributed Graphical User Interface (DDGUI) is a DUI in which all components are graphical components that can be dynamically distributed at run-time. The whole distribution is neither known nor established at design-time.

In Fig. 1, a drawing tool is used on a desktop computer. This application can be distributed in two different ways: either on the same device, or on several devices. On the same device, upper-right, the application can be remolded into another one or split into parts. With several devices, the toolbars can be displayed on a tablet and the colors of the pen can be chosen with a smartphone.

The research covers three dimensions: models, approach and software support (Fig. 2). The toolkit we have developed is based on a specific approach that is model-based. We have defined new models to describe a distributed system.

The Distribution Graph (DG) is the representation of a distributed system in a directed graph where vertices are either devices or users and arcs are links between them. Thus, it allows to model the users, devices and their connections. An example DG is depicted in Fig. 3.

This figure shows three named users: Jeremie, Boris and Yves. Jeremie has a Windows PC, Boris an Android smartphone, and Yves has a Linux PC. They are all connected to Beernet [2], a peer-to-peer system that provides a coherent view of the GUI state. Thanks to the DG, the toolkit knows who the users are and what devices they use.

The JayTk toolkit works on most current operating systems and is currently integrated in a SpinOff startup called Usidistrib [3]. The toolkit’s structure is depicted in Fig. 4.

Figure 1: An example Dynamic Distributed Graphical User Interface.

Figure 2: The three dimensions covered.

Figure 3: An example Distribution Graph.

Figure 4: The structure of the JayTk toolkit.

References
Synchronisation-free programming for large-scale Internet applications

Keywords : Cloud computing; Scalability; Consistency; Programming.

Christopher Meiklejohn, Peter Van Roy

Abstract – Traditional approaches to distributed application design break down for large numbers of devices when there is shared mutable data. The traditional approaches are either not scalable (because they use strong consistency) or extremely difficult to program with (because they use eventual consistency). Synchronisation-free programming provides an alternative that is both scalable and easy to program. This approach is based on the recent discovery of a distributed data structure called a Conflict-free Replicated Data Type (CRDT). Using CRDTs as the foundation, we show how to develop large-scale Internet applications with an easy-to-use programming model, called Lasp, that supports functional reasoning and programming techniques.

Since the advent of Web 2.0, we are witnessing an amazing growth of Internet-based interactive services. Two kinds of service in particular are quite successful at scaling to extreme numbers of clients and amount of data (see Figure 1): “embarrassingly parallel” algorithms (such as MapReduce and SETI@Home) and Content Delivery Networks (such as BitTorrent). It is easy to scale up the former, because by definition they decompose into subproblems that share nothing. It is also relatively easy to scale up content delivery, because the data being distributed is immutable (e.g., movies). In both cases, the only synchronisation needed remains small scale, i.e., between a small number of computing nodes.

But there is an essential, third kind of service that is not covered by these two cases: large-scale applications that use shared mutable data. Simple solutions impose centralisation (inside a data center, see Figure 1), and advanced solutions (using so-called eventual consistency) remain extremely difficult to program and understand. Our research, concretized in the SyncFree project [1], proposes an alternative solution that addresses both issues. Our solution is both much simpler for developers and allows decentralised implementation (close to users, at the “edge”).

Consider the simple example of maintaining a shared counter, for example to count advertisement views in an online or mobile application. In a naive implementation, each view remotely increments one shared integer. Serialising updates in this way may work for a low volume advertisement agency, but does not scale up to millions of users. A centralised counter is a serialisation bottleneck, does not support offline mobile devices, and is blocked during a data center failure or disconnection.

Many advanced large-scale application use another technique, called eventual consistency (EC). EC improves scalability by weakening the synchronisation requirements. EC allows concurrent updates to proceed without synchronisation, and propagates and merges them in the background. An EC approach to the advertisement view application might decompose it into partial counters located around the network, would increment each counter locally, and would propagate the partial counts in a peer-to-peer manner. The difficulty here is: how to support high numbers of concurrent, high-volume, continuous flows of count information, without losing an update or counting it multiple times? In the presence of failures, this is extremely difficult to get right.

The SyncFree project uses a new approach to eventual consistency. It avoids the difficulties of the traditional approach while maintaining the advantage of scalability. This approach is called Conflict-free Replicated Data Types (CRDTs) and it was discovered recently by SyncFree project partners [2]. Using CRDTs makes it possible to do concurrent updates without synchronisation. CRDTs are constructed to satisfy a formal property called Strong Eventual Consistency: if two data nodes see the same updates, then they have equivalent state. Many common data structures, such as registers, counters, sets, graphs, dictionaries, and so on, have been efficiently implemented as CRDTs.

Using CRDTs as the basic data structure, we have developed a programming model for synchronisation-free programming called Lasp 1. Our initial design provides powerful primitives for composing CRDTs, which lets us write long-lived fault-tolerant scalable distributed applications. Given realistic models of node-to-node communication and node failures, we prove formally that a Lasp program can be considered as a functional program that supports functional reasoning and programming techniques [3]. We have implemented Lasp and have developed several nontrivial applications. We are extending our current prototype into an industrially validated general-purpose language that uses synchronisation as little as possible.

References


Figure 1: SyncFree project: traditional technologies versus coordination-free sharing.

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1Lasp stands for Lattice Programming.
Leakage-resistant authentication and encryption from symmetric cryptographic primitives

Keywords: Encryption; Authentication; Side-channel attacks; Leakage resilience.

Olivier Pereira, François-Xavier Standaert, Srinivas Vivek

Abstract — The need for secure communication keeps increasing in a world in which small connected “things” will outnumber the world population within 2 years (Gartner, Nov. 2015). The challenges raised by this need are particularly acute when objects are readily accessible to an adversary: in this context, security is not only an algorithmic problem, but also a physical problem as devices may leak sensitive information through their power consumption or electromagnetic radiations.

In this research, we investigate the design of authentication and encryption schemes that are both efficient and leakage-resilient, in the sense that security can be maintained even if a device continuously leaks information about its internal state. We develop new security models that account for information leakages, and propose new block-cipher based constructions that cause a marginal cost compared to non-leakage-resilient constructions. Finally, we prove the security of our constructions based on traditional assumptions on block-ciphers and on the possibility to simulate leakages, an empirically verifiable property of a device.

Leakage-resistant cryptosystems aim to maintain security in situations where their implementation leaks physical information about their internal secrets. Because of their efficiency and usability on a wide range of platforms, solutions based on symmetric primitives (such as block ciphers) are particularly attractive in this context.

So far, the literature has mostly focused on the design of leakage-resilient pseudorandom objects (e.g. PRGs, PRFs, PRPs). We now consider the complementary and practically important problem of designing secure authentication and encryption schemes. For this purpose, we follow a pragmatic approach based on the advantages and limitations of existing leakage-resilient pseudorandom objects, and rely on the (arguably necessary, yet minimal) use of a leak-free component. The latter can typically be instantiated with a block cipher implementation protected by traditional countermeasures, and we investigate how to combine it with the more intensive use of a much more efficient (less protected) block cipher implementation.

Based on these premises, we propose and analyse new constructions of leakage-resilient MAC and encryption schemes, which allow fixing security and efficiency drawbacks of previous proposals in this direction. One of our constructions, illustrated in Figure 1, is reminiscent of the widely used CBC-MAC mode. However, it uses a leak-free initialization step in order to derive a one-time key from a unique initialization vector (IV), and then expanded using a leakage-resilient stream-cipher whose output is xored with the message blocks.

A natural direction for future works consists in addressing the challenge of building authenticated encryption schemes with associated data (AEAD) that would be both misuse-resistant and leakage-resilient.

Figure 1: Leakage-resilient MAC.

Figure 2: Leakage-resilient encryption scheme.

References


We leverage state-of-the-art accomplishments in SMPC to design SIXPACK [1]. Under SMPC, the computing entities do not gain visibility into neither the input nor the outputs of the computation. To facilitate the exchange of routes among their members, IXPs provide Route Server (RS) services to dispatch the routes according to each member’s peering policies. Nowadays, to make use of RSes, these policies must be disclosed to the IXP. This state of affairs raises privacy concerns among network administrators. We design SIXPACK, a RS service that leverages Secure Multi-Party Computation techniques to keep peering policies confidential, while maintaining the same functionalities as today’s RSes. We assess the effectiveness and scalability of our system using traces of data from one of the largest IXPs in the world.

Protecting the privacy of sensitive business data on the Internet is a topic that is subject to ever-growing attention in a highly-connected, insecure world. We focus on the goal of preventing the leakage of business policies in Internet routing. With the advent of Internet eXchange Points (IXPs) as the new physical convergence points for Internet traffic, new privacy concerns arise. This is because IXPs offer centralized Route Server (RS) services for ranking, selecting, and dispatching routes to their member networks. However, to benefit from the centralized services, IXP members need to divulge private information, such as business peering relationships to the IXP.

The SIXPACK route dispatcher system. We propose a practical solution for protecting confidential peering policies of the IXP members, i.e., the specification of what BGP routes a member is willing to announce to other members, by executing today’s route server services on critical data via secure multi-party computation (SMPC) [1]. Under SMPC, the computing entities do not gain visibility into neither the input nor the outputs of the computation. We leverage state-of-the-art accomplishments in SMPC to design SIXPACK, the first IXP route server service for ranking, selecting, and dispatching BGP routes without leaking any confidential business peering information. In our design, two non-colluding computing parties, called Route Server 1 and Route Server 2, carry out the dispatching of BGP routes (see Figure 1). We consider two different route dispatch approaches, which differ in the number of routes that are exported to the IXP members:

- **SINGLE**: Exporting only the best route. In the SINGLE dispatch approach, SIXPACK collects BGP announcements from all the IXP members, computes the best exportable route for each member, and dispatches to each member its selected route.
- **ALL**: Exporting all permissible routes. In the ALL dispatch approach, SIXPACK relays all exportable BGP announcements between its members. That is, SIXPACK performs route filtering so as to enforce members’ export policies, but does not select best routes for its members.

To clarify our security assumptions, our threat model focuses on parties in the SMPC computation that have a perfect view of all BGP routes announced through the IXP but do not monitor the actual flow of traffic. We assume that both parties adhere to the protocol but attempt to infer as much information as possible about the private inputs (i.e., export policies) of the IXP members. Our goal is to prevent each of the parties from learning anything about these private inputs.

Implementation and evaluation. We implemented a fully functional prototype for SIXPACK. For implementing the SMPC part of the system, i.e., the two RSes components shown in Figure 1, we use the ABY framework [2]. ABY is implemented in C++ and provides low-level primitives for building SMPC functions. The computation of an SMPC function consists of an offline phase, which can be precomputed, and an online one, which depends on the real inputs. For implementing the rest of the system, i.e., the distribution and processing of all the BGP update information among RSes and IXP members, we used Python. We assess our system using a trace of BGP updates from one of the largest IXPs worldwide, with more than 600 members. Our results highlight the following:

- While SMPC is (as expected) the costliest part performance-wise, our results establish that the online phase is even at worst below 20 ms. The worst setup and online runtime we measured in our evaluation were 72 ms and 19 ms, respectively for 32 inputs in the SINGLE case.
- Our unoptimized SIXPACK prototype is capable of processing BGP announcements in real time with a latency of 274 ms at the 99th percentile and negligible communication overhead, even without precomputing the offline phase of the SMPC.
- We measured the amount of communication that is required by SIXPACK during our evaluation of our datasets. We found that the average bandwidth requirements are: no more than 2.79 Mbps between the two route servers, no more than 70 Kbps between a member and the two route servers.

Future directions. We believe that future research should concentrate on extending the functionality of privacy-preserving RS services. One interesting direction is extending SIXPACK to receive as input (beyond members' export policies) also member’s (private) local preferences over BGP routes and then running SMPC to select the best (exportable) path per member.

References


Identification of a molecular signature of cycling hypoxia for breast cancer prognosis: a large scale data analysis approach

Keywords : Machine learning; Feature selection; High throughput genomic data; Cancer prognosis.

Pierre Dupont, Samuel Branders

Abstract – Machine learning methods and original statistical validation protocols were developed to define a novel prognosis model for primary breast cancer. This prognosis model could help clinicians to better treat patients suffering from breast cancer. It outperforms significantly state-of-the-art prognosis kits and nicely complements clinico-pathologic criteria currently used to orient treatments. The molecular signature at the core of this result is modeling the phenotype of tumors under cycling hypoxia, i.e. the cyclic lack of oxygen of a growing tumor.

The more a tumor grows the less oxygen it receives as this source of energy gets exhausted in its surrounding environment. Tumors go through various processes to compensate for this lack of oxygen (known as hypoxia) including vascularization: the growing of new blood vessels. Their level of oxygen is then back to normal (normoxia) before a further growth and oxygen deprival phase. The more a tumor is exposed to varying levels of oxygen (i.e. cycling hypoxia), the more it is expected to develop mechanisms to survive under this stress. The phenotype of tumors conditioned by cycling hypoxia is thus expected to be related to their ability to grow and, eventually, to characterize their aggressiveness. The above hypothesis has proved successful to form the basis of a powerful prognosis tool for breast cancer [1, 2].

Figure 1: Gene expression signature identified from 20 tumor cell lines under normoxia versus cycling hypoxia.

At first glance, these scientific questions purely belong to cancer research but they also raise computational and statistical challenges for which the expertise of data scientists is required. Gene expression measurements on cell line data were performed on DNA microarrays from the Affymetrix GeneChip Human Genome 1.0 ST platform. This technology interrogates 28,869 well-annotated genes with 764,885 distinct probes. Twenty cell lines under 2 conditions (normoxia versus hypoxia) represent more than 30 million expression values at the probe level. Identifying an informative signature (see Figure 1) from such a large data collection requires a careful data analysis pipeline. From a statistical viewpoint, this amounts to find a needle in a haystack since it includes orders of magnitude more dimensions (the gene expression values) than samples. Validation on breast cancer data raises additional challenges to transfer a signature estimated on cell lines to real tumor tissues. Dedicated machine learning methods [3, 4], implemented in grid or cloud computing architectures, are also needed to limit the risk of overfitting which would lead to define a model looking good on an initial collection of patients but which would generalize poorly to new patients.

Figure 2: The proposed prognosis model based on a cycling hypoxia signature is able to detect false positives from the Nottingham Pronostic Index (NPI) currently used in clinics to orient treatments of primary breast cancer.

The cycling hypoxia prognosis model has shown to significantly outperforms state-of-the-art kits for breast cancer prognosis. This is especially true for a sub-population of ER+, HER2-, node negative patients. This result is particularly interesting since the prognosis is highly uncertain for this sub-population when considering only clinico-pathologic criteria, which are commonly used in clinics. In other words, the identified signature opens new opportunities for specific treatment guidance on top of clinical criteria routinely used.

Ongoing work aims at transferring these promising results reported for breast cancer to the prognosis of colorectal cancer. This is motivated by the fact that the modeling of cycling hypoxia is expected to be also relevant in this case and by the high prevalence of colorectal cancer. This work results from a joined research project between ICTEAM researchers and the team of Prof. O. Feron at IREC, the UCL Institute for Clinical and Experimental Research.

References

bandicoot: a toolbox for mobile phone metadata

Keywords: Mobile phone; Metadata; Machine learning; Behavioral indicators.

Yves-Alexandre de Montjoye, Alex Pentland, Luc Rocher, Julien Hendrickx
(Collaboration with MIT)

Abstract – bandicoot is an open-source Python toolbox to help data scientists analyze mobile phone metadata. With only a few lines of code, bandicoot loads your datasets, visualizes your data, performs analyses, and exports the results.

Every time we send or received a text or a phone call, our mobile phones generate metadata: who we call, at what time, for how long, and from where. Collected at large scale, they have been used to design transportation systems, planning disaster responses, and fight epidemics. [1] While the use of machine learning algorithms on mobile phone metadata has been evolving fast, it currently lacks the standardization needed to thrive. Numerous crucial implementation choices are often lost from one research paper to another making it hard to replicate results, to quantify the impact of new methods, and to transfer knowledge.

We have introduced bandicoot, an open-source Python toolbox, to solve these issues. bandicoot extracts more than 160 robust behavioral features from mobile phone metadata, and focuses on making it easy for researchers and practitioners to load metadata and compute robust features from them.

bandicoot indicators fall into three categories (see Figure 1):

1. **Individual indicators** (e.g. percent of nocturnal interactions, time it takes someone to answer text messages) describe an individual’s phone usage.
2. **Spatial indicators** (e.g. entropy of visited antennas, radius of gyration) describe mobility patterns.
3. **Social network indicators** (e.g. clustering coefficient, assortativity) describe individuals’ social network and compare their behaviors with those of their contacts.

Emphasis is put on correctness and consistency through numerous unit tests covering 91% of the source code, domain-specific code detecting incorrect entries, and reporting variables to assess data quality or potential data issues.

bandicoot’s behavioral indicators were, for instance, used to predict users’ personality traits [3] – the Big Five indicators (neuroticism, extraversion, etc.) – resulting in accuracies up to 70% better than random. Similar methodology has recently been used to predict the gender of users in low and medium income countries.

Figure 2 (reproduced from [2]) shows that a training set of 10,000 people is enough to reach an accuracy ranging from 74,3% to 88,4%.

Figure 2: Gender prediction reaches 74,3% accuracy with a training size of 10,000 people.

During the “Data for Development” challenge, an international research challenge [4] using a massive anonymized dataset provided by telecommunication company Orange, bandicoot was used to address socio-economic development question in Ivory Coast. Best contributions explored disease containment for country-wise epidemics, social divisions, or optimization of public transportation.

References

[2] Jahani, E., Sundsøy, P. R., Bjelland, J., Iqbal, A., Pentland, A., de Montjoye, Y. A. “Predicting Gender from Mobile Phone Metadata”.

Figure 1: bandicoot uses individual, spatial, and social features.

bandicoot is currently used at large scale experiments by carriers (e.g. Orange, Telenor), NGOs, and international organizations (World Bank).
Scientific Highlights 2016

Sport sciences through data sciences

Keywords: Machine Learning; Sport.

Dimitri de Smet, Michel Verleysen, John A. Lee

Abstract — Machine learning aims at modeling relationships or patterns in data that cannot be derived from domain-experts equations. This modelisation can be used to make predictions or to improve the domain-expert knowledge itself. The purpose of this project is to tackle sport science problems using machine learning techniques, taking advantage of the relatively new fact that zillions of geolocalized tracks are made publicly available on the web (Garmin, Nike+, Strava, RunKeeper, ...)

Available tracks are tuples of geolocalized points associated with timestamps recorded by athletes with specific devices that can eventually record more parameters like heart rate, cycling torque, cadence, accelerations, temperature or barometric pressure.

We summarise hereafter four parts of this project.

Heart Rate Adaptation to Athlete’s Power Output

Many tracks are provided with continuous heart rate monitoring. Tracks allow estimation of the athlete’s continuous power output. We can then identify the relationship \( f() \) between Heart Rate \( HR(t) \) and Power Output \( PO(t) \).

\[
HR(t + 1) = f(PO(t))
\] (1)

The expected benefits of this part are as follows:

- Improvement of the general model of heart rate adaptation to athletes’ power output with a sample size exceeding current domain specific studies.
- Possibility of continuous monitoring of athletes’ fitness level at minimal cost by parsing their activities

Difficulty of Routes

A good intuition of the difficulty of a route (a tuple of geolocalized points without timestamps) is given by the average pace \( \text{pace} = k \times \text{speed}^{-1} \) athletes can achieve on it. As routes were not run by the same set of athletes, we have to solve two coupled problems: evaluating the routes, and evaluating the athletes. We propose to do this with the help of a matrix completion algorithm (without going into details, the problems seem at first sight quite similar to the recommendation problem, which is well known in the machine learning literature). This will give us difficulty ratings for the routes that we can then use to fit a regression model \( d() \) that takes the routes’ features (distance, total ascent, ground type, ...) as inputs. The model can thereafter serve as objective measure of the difficulty of new routes that were not run yet.

\[
difficulty = d(textroute)
\] (2)

The expected benefits of this part are as follows:

- Proper evaluation of sport routes (running, cycling, ...) helps athletes to prepare specific events and to optimize their pace on race days.
- An objective measure of the difficulty of a race would help organizers to establish new routes or to weight different races of a championship.

Data Preprocessing

Gps traces contain noise, partly because of the devices technology (poor elevations resolution and need for continuous satellites visibility) and because of users misuses. These problems will first be addressed by prepossessing the data. For instance we will deal with elevation correction, smoothing, cropping and discarding tracks.

Figure 1: Louvain-La-Neuve Running Heatmap.

Figure 2: Heart Rate Simulation.
Modern technology allows huge amounts of data to be collected, with many recorded observations, as well as many variables. High data dimensionality often means that interpretation by a human analyst is difficult. Similarly, automated processing is hindered by the so-called curse of dimensionality. This refers to a series of counter-intuitive phenomena that affects high-dimensional spaces. A typical example is the phenomenon of distance concentration. In high-dimensional spaces, distances are poorly discriminant and all points seem to lie far from each other.

In this context, methods of dimensionality reduction (DR) can ease both manual and automated analysis. For instance, DR can embed data in 3D or 2D spaces that can be easily be visualised and explored. Less drastic DR, from thousands or hundreds of dimensions to only a few dozens, can mitigate the curse of dimensionality in automated data processing tasks like regression, function approximation, etc. Linear DR has been known for quite a long time, with methods like principal component analysis, which projects data onto a lower-dimensional subspace. More recent methods are also available. These are powerful and can embed data in a nonlinear fashion. To some extent, these methods can thus learn from data some underlying, nonlinear manifold, instead of a linear subspace. Several approaches can be followed to achieve this task: auto-associative neural networks, spectral graph embedding, kernel extensions of PCA, etc. Yet another well known principle consists in finding a low-dimensional representation of that best preserve pairwise relationships, like distances or similarities. Current research in our team investigates this last option. Pairwise similarities quantify the probability of two data points to be neighbours. Data embedding is then obtained by trying to reproduce in a low-dimensional space the neighbourhoods observed in the initial data space. Several ways to improve this method of stochastic neighbour embedding (SNE) are investigated:

- Improvement of the loss functions. These measure the discrepancy between the low-dimensional neighbourhoods and their high-dimensional counterparts. Specifically, mixtures of divergence functions have improved the DR results.
- Multi-scale neighbourhoods. Most SNE variants involve neighbourhoods with a single, fixed size, chosen arbitrarily by the user. Our approach explores combinations of neighbourhoods with multiple sizes, in order to capture data structure on all scales, from local to global. Here too experimental results have shown more faithful rendering of data.
- Scalable implementation of multi-scale SNE. This ongoing project aims at making DR applicable to large data sets within reasonable computation times.

Our team also studies quality assessment of DR and . As an unsupervised learning task, DR is difficult to appraise and we have thus proposed several quality criteria, as well as a unifying framework.

Abstract – Visualisation and processing of high-dimensional data can be made easier by dimensionality reduction, which attempts to represent data with few variables or features and minimal information loss. Our research projects investigate particular family of state-of-the-art methods of dimensionality reduction, called stochastic neighbour embedding. Improved and multi-scale neighbourhoods, and scalable implementation are our current objectives. Another line of research studies quantitative criteria to assess the quality of dimensionality reduction results.

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- Scalable implementation of multi-scale SNE. This ongoing project aims at making DR applicable to large data sets within reasonable computation times.
Abstract – This research activity deals with the control of ice cream crystallization. More precisely, a controller for the viscosity has been designed and implemented on a pilot-scale ice cream crystallizer.

In crystallization processes, an important challenge is to control the quality and/or the properties of the product. In the case of ice creams, it is well known that the quality, that is the hardness and the texture of the ice cream, depends on the ice crystal size distribution (CSD). For example, depending on the mean crystal size, or more precisely on the dispersion of crystal sizes (that is on the shape of the CSD), the obtained texture of the ice cream is more or less grainy. Indeed, an ice cream with a narrow ice CSD and a small mean ice crystals size is smoother and more palatable. But it can also be interesting, in a production point of view, to control other properties of the ice cream, as its viscosity. Indeed, the ice cream market is characterized by a variety of products that can be classified in particular in term of their final packaging. Each type of final product is characterized by a specified viscosity: for instance a lower viscosity is required for large carton packaging than for cones. One of the objectives of ice cream crystallization processes is therefore to produce an ice cream of specified viscosity.

The dynamics of a crystallisation process can be given from mass and energy balances in the form of a population balance model in which one of the independent variable is the size of the crystals. The resulting model is a distributed parameter model, also known in mathematics as an infinite-dimensional system. For the purpose of the control design and implementation, the model has been reduced by considering the method of moments.

The study of the crystallization system shows that the viscosity of the ice cream can be expressed as a function of the ice temperature and the third moment of the ice CSD. As a consequence, it is not necessary to control the shape of the CSD itself: only the control of the third moment is needed. A careful analysis shows that the saturation temperature (measured on-line) can be efficiently used to appropriately describe the dynamics of the third moment.

The control design couples a linearizing control (to account for the nonlinearities of the system dynamics) with a Smith predictor (to compensate the time delay in the on-line measurement of the saturation temperature at the outlet of the crystallizer). It finally takes the form of a cascade controller with an inner loop with the saturation temperature as the controlled variable and the evaporation temperature, and an outer loop where the compressor rotation speed controls the evaporation temperature. The controller has been successfully implemented on the pilot-scale ice cream crystallizer of the IRSTEA in Antony (Paris).

References

Scientific Highlights 2016

Plant growth modelling

Keywords: Plant growth; Modelling; System identification.

Denis Dochain, Heather MacLean

Abstract – This research activity deals with the development and identification of a simple mass balance model for plant growth. Photosynthesis and respiration have been selected as key reactions for biomass production. The model has been developed using a mass balance approach.

This research activity has been initiated under the auspices of the European Space Agency (ESA), and more in the framework of the MELISSA project. The MELISSA (Micro-Ecological Life Support System Alternative) project aims to develop technology for a future regenerative life support system for long term manned space missions. Developed by the European Space Agency, the concept is to use microorganisms and plants to regenerate the atmosphere, recycle water, and to produce food for the crew on such missions. An important part of the MELISSA loop is the growth of higher plants in a controlled greenhouse environment for the production of food and oxygen from 'waste' carbon dioxide. A model of plant growth is required for the prediction and eventual control of this compartment. The model must be applicable at normal operating conditions, as well as during failure and stress conditions. The main control objective will be to provide a certain desired 'flow' of biomass from the plant chamber as food for the crew. Both quantity and nutritional requirements will need to be maintained.

The model has been further developed by considering development stages, in order to account for the change in metabolism. It is indeed known that biomass partitioning (the allocation of new assimilated carbon to the growth of different organs - leaves, roots, fruits, etc.) changes during development, and that these changes in partitioning could be linked to changes in metabolism that influence the flux of oxygen and carbon dioxide. The incorporation of development stages has been done by considering a transition test based on the photosynthetic quotient, which is the ratio of oxygen produced by the plants to the $CO_2$ consumed.

Figure 1: Schematic view of the greenhouse.

Two plants, lettuce and red beet, have been studied in the context of the MELISSA project. Further developments have been performed with another plant, Arabidopsis, from experiments designed and implemented at the LEPSE (Laboratoire d’Ecophysiologie des Plantes sous Stress Environnementaux) of the INRA in Montpellier.

Plants are complicated systems. Their growth and development involve a large number of interconnected processes and reactions. Plant models cannot incorporate all of these processes, and therefore those that are most important need to be selected. To simplify the selection process, only total biomass production was considered, and therefore biomass partitioning was not included at this stage. In the first model selection, only photosynthesis (??), photorespiration (??), and mitochondrial (or dark) respiration (??) were considered. These reactions were selected because they are the main reactions influencing the production of biomass, as well as the exchange of carbon dioxide and oxygen between the plant and the atmosphere.

\[
CO_2 + H_2O \xrightarrow{\text{Light}} Biomass + O_2 \tag{3}
\]

\[
Biomass + O_2 \xrightarrow{\text{Light}} CO_2 + H_2O \tag{4}
\]

\[
Biomass + O_2 \rightarrow CO_2 + H_2O \tag{5}
\]

Figure 2: Model validation for red beet.

References


Abstract – This research activity deals with the study of wine making. More precisely, metabolic engineering is considered to better understand the production of the organoleptic properties of the wine. Further, a controller has been designed and implemented for a multi-stage reactor for which each reactor corresponds to a specific physiological state of the yeast during wine making.

During the alcoholic fermentation, sugar is converted to ethanol and carbon dioxide, but many other compounds are removed from the must and a large set of by-products are formed that affect the sensorial properties of the wine. Optimising the control of alcoholic fermentations for wine-making is a difficult challenge. Unlike some other kinds of industrial fermentations, such fermentations do not aim to maximise the concentration or yield of a defined metabolite, or the productivity of the process. In wine-making, the main objective is to optimise product quality, which is very difficult to quantify. From now on quality marker molecules are identified and could partly describe the major organoleptic qualities or defaults. They are issued from complex and numerous metabolic pathways inside the yeast cell and the metabolic engineering could be used for this modelling. The analysis considers Metabolic Flux Analysis (MFA) and first results identify 79 intracellular reactions with 70 internal metabolites and 9 external metabolites. The objective is to reduce substantially the reaction network and to come up a reduced number of macroscopic reactions that can be validated on experimental data (including data of amino-acids and sulfur compounds that intervene in the organoleptic properties of the wine).

In parallel to the metabolic engineering modelling, an experimental setup has been designed with the objective to better characterize the physiological state of the yeast at different stages of the ethanolic fermentation (run in batch conditions). It is based on the concept well-known in chemical engineering of the time-space equivalence that allows to transpose batch reactor operation into steady-state plug-flow reactor operation. The SPO (Sciences pour l’oenologie) of the INRA in Montpellier has been setting up a cascade of four reactors that approximates the behaviour of the plug flow reactor in an optimised way. The main advantage of this configuration is to have, in stable conditions, different physiological states of the yeast in each reactor corresponding to key transient states of the batch fermentation.

The main challenge is to design and implement a control scheme that allows to reach each of these physiological state and to maintain them in stable conditions, with major constraints of the feed flow rates. Such control law have been analyzed and implemented on the SPO experimental setup. This study has received the Application Paper Prize at the IFAC World Congress in 2014.

References
Analysis and control of tubular reactors

Keywords: Tubular reactor; Distributed parameter systems; Infinite dimensional systems; Control.

Denis Dochain

Abstract – This research activity deals with the analysis and control of tubular reactors that cover a large class of distributed parameter in the field of (bio)chemical systems. Results cover a wide spectrum from observability/controllability analysis to the implementation of controllers on industrial processes via the stability analysis of the multiple steady states.

Tubular reactors cover a large class of (bio)chemical systems as encountered in industry and real-life applications. They are basically characterized by the non-homogeneity of the reacting medium within a confined volume (the reactor), and their dynamics are described by partial differential equations. With that respect, they belong to the class of dynamical systems known as infinite dimensional systems.

There are basically two classes of tubular reactors, one for which the hydrodynamics are purely convective (they are known as "plug-flow" reactors), the other described convective-diffusive hydrodynamics. Plug flow reactors are known in chemical reactor design as the best basic reactor configuration in the sense that it allows to maximize the conversion. Convective-diffusive reactors represent an intermediate class of reactors between the plug flow reactor (when the diffusion coefficient(s) is(are) to zero) and the continuous stirred tank reactor (CSTR) (when the diffusion coefficient(s) tend(s) to infinity).

The research activities are oriented in multiple directions.

- Analysis of the existence and stability of multiple equilibrium profiles in tubular reactors (e.g. [?])
- Numerical and mathematical analysis of the reduction methods applied to tubular reactor partial differential equations in order to obtain a set of ordinary differential equations (e.g. [?]?)
- On-line state and parameter estimation of tubular reactors, including the application of ETBE synthesis process and denitrifying biofilter (e.g. [?])
- Control design for tubular reactors, including adaptive extremum seeking approaches (e.g. [?]?)
- Control applications, including anaerobic fixed bed reactors and denitrifying biofilter (e.g. [?])

As a matter of example, one key issue is to emphasize the conditions under which multiple equilibrium profiles may appear non-isothermal tubular reactors. On one hand, it is well-known in chemical process dynamics that the CSTR may exhibits three equilibrium points. On the other hand, the plug flow reactor can exhibit only one equilibrium profile due to the form of its boundary condition (only one boundary condition at the reactor inlet characterized by a scalar relation). One will therefore expect that the convective-diffusive configuration will be able to exhibit multiple equilibrium points if it is far enough from the plug flow reactor and close enough to the CSTR. This situation has been carefully studied and the results provided in [?] shows that multiple equilibrium profiles may exist if the diffusion coefficient(s) is(are) large enough.

References

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Irreversible thermodynamics and process control

Keywords: Tubular reactor; Distributed parameter systems; Infinite dimensional systems; Control.

Denis Dochain

Abstract – This research activity deals with the analysis of the link between irreversible thermodynamics, system theory and process control. The objective is to find out new control design paradigms based on the knowledge of thermodynamics and its role in the energy representation in reaction systems.

The universal character of classical thermodynamics comes from the fact that it does not deal with a restricted class of systems and does not depend on any model nor assumptions on the structure of matter. Unlike other branches of classical science (such as for instance mechanics or electromagnetics), thermodynamics does not try to explain the consequences of some formulated laws (as it is the case with the Newton’s laws or the Maxwell’s equations). The classical thermodynamic theory relates concepts that seem to be very different such as heat and work, and it explains equally well the working of a combined-cycle gas turbine power plant, of a fridge or of a car engine. Even in biology, thermodynamics shows up to be of primary importance. Indeed most of the exchanges in the human body are based on thermodynamic equilibria (e.g. the essential role of osmotic pressure for the kidneys). In chemical engineering, thermodynamics plays a central role in the modelling of chemical processes. Indeed typical phenomena that are going on in chemical reactors are heat transfers, chemical reactions, mass transfers... These all are phenomena that can be explained and modelled by the thermodynamics.

The analysis and design of control algorithms are largely based on system theory tools, and in particular on the stability “à la Lyapunov” which is indeed intrinsically based and justified on energy considerations. It is therefore natural to consider the thermodynamics theory for the control design of chemical processes. However, if in many situations it is rather easy to describe the Lyapunov theory in terms of energy for electrical and mechanical systems, this is unfortunately not the case for reaction systems. One central idea is to take advantage of the positivity of the state variables to consider Lyapunov functions that are not the classical quadratic functions, that are representative of the energy of mechanical and electrical systems, but not that of reactions systems, for which entropy-based functions are adapted.

Many research progresses have been performed over the past decade. These include in particular the following.

- The design of asymptotic observers, i.e. state observers that do not require the knowledge of the process kinetics, in a thermodynamically rigurous framework [7]
- The stability analysis of the continuous stirred tank reactor (CSTR), the reference case study in process control, by considering several thermodynamics based functions (entropy, entropy production, energy) [7]
- The design of power-shaping controllers by considering the entropy production as the potential function [7]
- The development of a general methodology for deriving the expression of the contact structure elements (i.e. the Legendre submanifold generating function and the contact Hamiltonian function) from the fundamental relation of a thermodynamic system and from its balance equations. Some features of the dynamical behaviour of a system with properties of its contact structure elements have been related [7]. For instance, an equilibrium point of the system is expressed by a critical point of the contact Hamiltonian function. Lyapunov’s first stability theorem has also been related to characteristics of the contact Hamiltonian function and of the Legendre submanifold generating function. This has allowed to state a sufficient stability criterion in terms of the contact structure of a system. This stability criterion has then been interpreted using physical considerations.

![Figure 1: The Gibbs’ relation in the thermodynamic state space.](image)

- The derivation of a thermodynamically stable evolution criterion, its use for selecting appropriate potential functions, as well as its use in comparing Hamiltonian system representation and Brayton-Mosser representation (considered in power-shaping control) [7]
- The analysis of the stability and passivity properties of a class of thermodynamic systems, i.e. those constituted by multiple spatially homogeneous dynamical subsystems modeled by ordinary differential equations, by considering the internal entropy production as a Lyapunov function when the system is isolated and as a storage function when the system interacts with the surroundings [7]

References

Adaptive extremum seeking control

Keywords: Extremum seeking; Real-time optimisation; Control.

Denis Dochain, Martin Guay

Abstract – This research activity deals with the design of control schemes that also allow to reach unknown optimal set-points. In the class of real-time optimization schemes, adaptive extremum seeking controllers are designed by using Lyapunov based theory in order to guarantee convergence to the unknown optimal setpoints.

Most control schemes documented in the literature are developed for the regulation to known set points or the tracking of known reference trajectories. In many applications, however, the control objective is to optimize an objective function that can be a function of unknown parameters, or to select the desired states to keep a performance function at its extremum value. The objective is then to perform real-time optimization. Extremum seeking is a possible option for doing so. The task of extremum seeking is indeed to find the operating setpoints that maximize or minimize an objective function. The main feature of adaptive extremum seeking control is that the design is a Lyapunov-based one that allows to provide guarantees of convergence to the unknown setpoints.

Two approaches can be followed in adaptive extremum seeking control: perturbation-based methods and model-based methods. Figure 1 shows a schematic view of the perturbation-based methods.

Figure 1: Schematic view of the perturbation-based extremum seeking control approach.

Different research progresses have been made in both types of approaches [7]. In perturbation-based extremum seeking control, several designs have been provided [7] including one synthesis within the standard framework of a classical PI (Proportional-Integral) regulator [7]. In the model-based approach, several case studies corresponding to different real-time optimization issues have been considered, e.g.

- Continuous bioreactor with one microbial growth reaction with unknown and known (Monod, Haldane) kinetics model structure [7]
- Fedbatch bioreactor with unknown [7] and known (Haldane) kinetics model structure
- Non-isothermal chemical reactors (Figure 2) [7]
- Tubular reactor with distributed heat exchanger [7], as well as with distributed feed [7]
- Cascade bioreactors with distributed feed
- Pulp and paper: paper machine (wet-end) [7]
- Drug delivery for medical treatment of patients [7]

Figure 2: Extremum seeking control applied to the optimization of the production of an intermediate product in a chemical reactor.

• ABS car braking system

References

Optimization and control techniques for cyber-physical systems: a new paradigm

Keywords: Cyber-Physical Systems; Control; Optimization.

Matthew Philippe, Benoît Legat, Raphaël Jungers
(Collaboration with MIT, Princeton, UIUC)

Abstract – Our research tackles fundamental control problems on complex systems, known as cyber-physical systems, with a particular focus on the rich class known as switching systems. We show that using state-of-the art optimization techniques, such as sum-of-squares programming, and taking into account the logical structure of the system, we may obtain powerful control tools for problems which, when asked on such complex systems, are known to be extremely hard in general.

Dynamical systems are models that describe the evolution in time of physical quantities. Typical modern systems involve many non-idealities, like disruptions in the feedback loop, nonlinearities, safety regulations (these can be listed as a set of requirements, sometimes with no clear mathematical translation), quantization due to communication channels, etc. Classical control techniques have not been designed for such situations, and making use of these classical techniques can lead to severely sub-optimal solutions. Typically, in order to address at best all these non-idealities, one resorts to the bisimulation technique, a fundamental tool to model and control Cyber-Physical Systems [6]. In a nutshell, this tool allows to represent a (complicated, continuous-time, nonlinear,...) system by a finite abstraction, say, an automaton.

Let us consider a practical and simple example, where a dynamical system is subject to failures of its controller. We represent failures by a state that evolves in time. When \( \sigma(t) = 1 \), it means that the controller behaves as expected, and when \( \sigma(t) = 2 \), it means a failure occurred. In many applications, we may assume that the failure mode cannot occur more than a few times in a row, and one may enquire about the behavior and stability properties of the system, under this assumption (see [4]). A typical way of approaching this example is by modeling it as a constrained switching system.

A switching system is a multi-modal system, that is, a system whose law of evolution can change from time to time. These models encapsulate the complexity of many different applications, ranging from the optimal design of drug treatment for viral diseases like HIV [1], to the analysis of consensus systems of autonomous agents [2], and other applied and theoretical topics [3].

They are described by the following difference equation, \( x_{t+1} = A_{\sigma(t)}x_t \) where \( x_t \in \mathbb{R}^n \) is the state of the system at time \( t \), \( \sigma(t) \) is the mode at time \( t \), and where we may consider that the sequence of modes must satisfy some rules. For our example, the rule could be "no more than 2 failures in a row". These rules can be encoded using an automaton, as in Fig. 1.

Applying classical control techniques to modern cyber-physical systems may lead to severely suboptimal solutions.

We developed several tools for the analysis of these systems, where the dynamics applied follows rules that can be modeled by an automaton. Our tools leverage techniques from automata theory, optimization, and Lyapunov control. They generalize and unify previously known techniques into a powerful analysis framework. The philosophy of our technology is not to apply blindly off-the-shelf optimization techniques (like so-called LMIs criteria available in the literature), but rather to leverage our knowledge of both the physical and logical structure of the system under study in order to apply a 'smart control' approach.

Figure 1: The automaton does not accept mode “2” for more than 2 times in a row. In our work, we leverage this combinatorial a priori knowledge of the system, combining it with semidefinite optimization [4] or sum-of-square techniques [5].

A well-known problem of the bisimulation technique is that, contrary to the simple example we have just seen, the size of the obtained automaton, which models the actual system, is typically huge. This often hampers our ability to use the bisimulation technique on practical systems.

Our approach alleviates this pitfall: instead of computing an abstraction of a particular system, and then looking for a control solution on it, our technique allows to co-design the abstraction and the control solution, thereby circumventing the curse of dimensionality by leveraging our physical knowledge of the system, without ending up with a huge representation of the system. We believe that such techniques will unlatch our ability to apply Cyber-Physical Control techniques to practical systems, which is currently strongly limited by the curse of dimensionality.

References

Scientific Highlights 2016

Safety-critical control of hybrid systems with applications to power electronics

Keywords: Physical constraints; Safety; Hybrid systems; Power converters.

Nikolaos Athanasopoulos, Raphaël Jungers

Abstract – Control of safety-critical systems requires to explicitly handle constraints acting on the states, the control inputs, the communication and the available computational power. Our research aims to address such challenges using advanced methods from control and optimization theory. Among others, our goal is to characterize (potentially non-convex) constraints sets in a safe way, compute the largest and smallest invariant sets and propose systematic ways of studying the stability and safety of hybrid systems.

Important applications are for instance in energy conversion, such as the DC-DC converter. In this case, the goal is to quickly reach predefined set-points without violating physical constraints on the output power, voltage and current and by respecting the constraints on the switching dynamics.

Hybrid systems, and more generally Cyber-Physical systems, are dynamical systems whose behavior involves both the laws of nature (let it be the Laws of Mechanics, of Biology, the Human Behavior,...) and computerized control commands, interacting in closed loop. Typical examples include: a set of autonomous robots whose behavior depends on the communication technology, and the network-topology of their interactions. Human-in-the-loop systems, like traffic control systems, where embedded and decentralized optimization algorithms have to cope with unpredictability and human interactions; a hybrid embedded control system which intertwines continuous-time (the physical laws) and discrete-time (the computerized control loop) dynamics. There are numerous other applications, from Wireless Control Networks to smart grids, embedded medical devices, Cyber-Physical Social Systems... All these situations need automated algorithms for making them evolve optimally under many constraints (safety, energy, resilience, sustainability,...).

When a set is invariant with respect to a system, all trajectories starting from it will remain there forever. Safety-critical systems are by essence subject to some type of constraints on their states or outputs, and thus the notion of invariance is crucial in these safety and viability problems [1]. Our work shows that these problems can be addressed efficiently, even for complex (nonlinear, nonconvex,...) safety constraints.

Modern algebraic optimization techniques open new ways for safety-critical control of cyber-physical systems.

Our results can be customized for the control of power systems, such as the DC-DC buck-boost converter shown in Fig. 2. The control problem concerns the regulation of the output voltage \( V_c \) and current \( I_L \) to a pre-specified point by controlling the switching \( d_1, d_2 \) of the two PWMs without violating hard constraints on the voltage, current, and maximum switching frequency. Our results provide ways to successfully address these problems. Moreover, we can ask more refined questions regarding safety and optimality, such as ‘what is the largest set of initial conditions that can be driven to the desired set-point’, ‘what is the most energy-efficient control strategy’ and ‘what is the control strategy that leads to the fastest convergence’.

References

Abstract – We present a new filtering technique to correct the votes of raters that are possibly spamming or trying to cheat a particular reputation system, such as Amazon, TripAdvisor or Ebay.

The World Wide Web is making more and more use of interactive ratings collected from various users: books are being evaluated in Amazon, movies are being rated in Movielens, web-users are even being judged in Ebay. This clearly is a form of voting but not all raters can be expected to be fully reliable or even honest. A rater on the Movielens database may give random ratings to movies he has not even seen, or a dishonest voter may give biased opinions just to favor his or her friends. From a commercial point of view, it is clear that web sites have a lot to earn by promoting confidence in such interactive rating systems. Ideally this would be achieved by penalizing raters that give random or biased ratings. Two questions ought to be addressed in this context: 1. What should be the reputation of the evaluated items? 2. How can we measure the reliability of the raters?

A natural way of tackling the problem of unreliable or unfair raters in reputation systems is to weight the evaluations of the raters. Hence the range of weights corresponds to a continuous scale of validation of the votes. These weights change via an iterative refinement that is guaranteed to converge to a reputation score for every evaluated item and a reliability score for every rater. At each step the reliability of a rater is calculated according to some distance between his given evaluations and the reputations of the items he evaluates. This distance is interpreted as the belief divergence. Typically, a rater diverging too much from the group should be distrusted to some extent. The same definition of distance appears in [1] and is used for the same issue. The strength of the new reputation system we describe in [2], is that it can be applied to any static network of raters and items and that it then convergences to a unique fixed point. Moreover, it can also be extended to dynamical systems with time-dependent votes.

We illustrate this method on an experiment involving a data set (supplied by the GroupLens Research Project) of 100,000 ratings given by 943 users on 1682 movies. The votes were ranging from 1 to 5. In order to test the robustness of our reputation system, we added 237 random raters to the original raters. In that manner, 20% of the users give random evaluations. Figure 1 gives the original (ordered) votes of the honest voters in blue and the (unfiltered) modified votes in green, when the spammers are also taken into account. Figure 2 gives the effect of the filtering operation on the same data, which clearly shows that the effect of the spammers has significantly been reduced. Figure 3 shows the distribution of the rater’s weight as a result of our filtering operation: the random voters are seen to be generally penalized by a much smaller weight. Notice that we could have used this to remove the group of users considered as outliers, but our reputation system prefers to provide a continuous range of rates, instead.

The main issues of this new reputation system are: the relevance of the measure, the robustness against different sort of attackers, the application of the method for any sort of data and the ease of understand the measure by users.

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**TECHNOLOGY TRANSFER**

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*Priority date
Based on research led by Pr B. Maq and Pr J.-J. Quisquater (UCL-ICTEAM/ELEN), intoPIX was set up in 2006 by J.-F. Nivart, Dr G. Rouvroy and Pr F.-X. Standaert. This independent image technology company benefits from world-class expertise and knowledge in image processing, cryptography and microelectronics and provides its customers with leading-edge image and video compression, security and hardware enforcement IP cores for audiovisual markets.

intoPIX has become the reference provider of JPEG 2000 tools for digital cinema and now leads the way with cost-effective solutions for digital acquisition, post-production, video over IP, contribution, storage and archiving. intoPIX technologies are dedicated to digital cinema, broadcasting, post-production, archiving, wireless, medical, aerospace, security, telecoms and any other audiovisual applications where image quality is crucial.

Next step: Deployment of the TICO product on the market.
- 100% market share in 4K cinema projection and more than 25% of the worldwide movie theatres equipped with the intoPIX technology: 2011.
- Spin-off creation: March 2006.
- Research project beginning: 2001

www.intopix.com
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e-peas was founded in 2014 by Dr G. Gosset and Dr J. De Vos, based on the conviction that the trillions of connected nodes of the Internet-of-Things to be deployed in the next few years will require disruptive solutions to avoid battery replacement. e-peas relies on 10 years of research, supported by the Walloon Region and the EU under the direction of Pr D. Bol and Pr D. Flandre (UCL-ICTEAM/ELEN), and on their patented disruptive technologies.

The unique approach of e-peas is based on both increasing the amount of harvested energy and drastically reducing the energy consumption of all power-consuming blocks in the electronic system. The spin-off company offers a portfolio of integrated circuits: management unit for photovoltaic and thermoelectric harvesters, microcontrollers and sensors solutions, all designed to improve system robustness and reduce application development time.

**Next step:** First prototype of microcontroller (early 2016).
- First prototype of ambient energy manager: **2015**.
- Spin-off creation: **December 2014**.
- “Proof of Concept” Grant: **2013**.
- “FIRST Spin-off” Grant: **2012**.
- Research project beginning: **2006**.

www.e-peas.com
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IBA, a spin-off company of UCL established in 1986, has become the world leader in proton therapy by developing its expertise in particle accelerators for cancer treatment. IBA, UCL (Pr B. Macq (ICTEAM/ELEN) and Pr J. Lee (IREC/MIRO)) and the Walloon Region teamed up in 2011, establishing the iMagX team, with a view to developing innovative imaging solutions to improve the accuracy of proton therapy.

Consequently, iMagX was launched as part of a public-private partnership, which ended in September 2015. So, 25 years after its creation, IBA has returned to its home university with some ioneering challenges that have enabled the UCL teams and IBA to achieve a world premiere: the first proton therapy guided by volumetric imaging in the treatment room at the University of Pennsylvania in Philadelphia.

Date of licence agreement: September 2015.
- “Proof of Concept” Grant : 2013.
- Research project beginning : 2011.
The Tessares solution leverages a new protocol standard, Multipath TCP (MPTCP), allowing one Internet session to be conveyed on several paths over different access networks.

Pr O. Bonaventure, Dr S. Barré and Dr G. Detal (UCL/ICTEAM/INGI) had already significantly contributed to the definition of the standard and the implementation of its reference software before being joined by D. Périquet, who brings a wealth of industry experience in the telecoms world.

Launched in 2015, Tessares is a technology start-up active in the R&D and commercialisation of software solutions that significantly improve the performance and quality of Internet access without requiring the deployment of additional resource-hungry infrastructure.

Next step: Proof of concept phase within Proximus lab and technical field trial within Proximus commercial ecosystem.
- Industrial partnership agreement with Proximus: 2015.
- Spin-off creation: March 2015.
- "FIRST Spin-off" Grant: 2013.

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